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PREFACE.

THE present volume is, in a large measure, the outcome of the gratifying reception with which the smaller work, "Know your Own Ship," published in the *Nautical Series*, met on its first and subsequent editions. The success of that book emboldened its Author to embark, at the suggestion of the publishers, upon the preparation of a larger and more important undertaking, the result of which is now presented to the reader in the hope that it will be found, not less than the former work, to merit the approval of that section of the shipbuilding world for whose needs it has been specially devised. A sketch of the plan of the book will be found at the end of this preface; it is therefore unnecessary here to do more than briefly outline the circumstances under which it has been written.

The work has taken four years to complete, the Author having been unable to devote more than his leisure hours to its composition. A careful study of some years' duration, carried out in that centre of the steel trade, the Cleveland district, has afforded the necessary basis for the first two chapters, while the subsequent chapters are the result of the Author's daily experience in the profession of ship construction and maintenance. The book has been copiously illustrated, and no expense has been spared in the preparation and execution of diagrams intended to amplify and elucidate the text. These have been placed in close juxtaposition to those portions of the work to which they refer, the Author conceiving that they will thus prove more readily available for purposes of reference than if they had been published as a separate volume, as is sometimes done in works of this class. The whole subject has been treated from a practical point of view, and the requirements of students, ship superintendents, shipbuilders, and marine engineers have been carefully studied. The Author desires to express his thanks to the Cunard Steamship Co., Liverpool, for the permission to reproduce illustrations and details of their Royal Mail Steamers 'Campania' and 'Lucania'; to Messrs. Alfred Holt & Co. (Ocean Steamship Co., Liverpool), for permission to illustrate one of their latest cargo steamers; and also to the following shipbuilders,—Messrs. Armstrong, Whitworth, & Co., Wm. Doxford & Co., Ropner & Son, J. Priestman & Co., and Messrs. Sir Raylton Dixon & Co., Middlesbrough, for permission to illustrate particular vessels built by them, and some details of their methods of construction.

Further, he desires to record his best thanks to his friend, J. Bolam, Esq., Head Master, Government Navigation School, Leith, for his kindly assistance in reading over part of the manuscript.

THOMAS WALTON.

LONDON, *June* 1901.

NOTE TO THE SECOND EDITION.

THE rapid sale of the first large edition of this work, in six months from the date of its publication, has proved extremely gratifying to the Author, and has rendered the issue of a Second Edition necessary. He therefore takes the opportunity thereby presented of expressing his sincere thanks to the press, and to all those who have recorded their opinions of the work, for their criticisms, which have, without exception, been highly appreciative, generous, and encouraging.

T. W.

LONDON, *January* 1902.

PLAN OF BOOK.

Chapter I. is a condensed description of the processes of the manufacture of steel and iron, from its crude state in the form of ore, to the finished product in the form of ship plates, forgings, bars, etc., particularly noting those constituents of the material which are essential to the production of good ship steel or iron, and those which, if in excess, introduce objectionable qualities into the metal.

Chapter II. treats of the strength and quality of ship steel and iron as a result of the proportions in which the various constituents referred to above are present in the metal, and the particular processes through which the material passes in the course of manufacture.

A description is also given of the tests applied in order to definitely ascertain both the strength and quality.

Chapter III. explains what is meant by a vessel being 'Classed,' and the nature of the work of those Societies empowered to assign loadlines.

Chapter IV. is a general introduction to the subject of ship construction, drawing attention to the principal structural features, and the alternative modes in which a vessel may be built.

Chapter V. deals with the various forces which are exerted upon the hulls of ships, *tending* to strain them and produce deformation; and shows also how to estimate the maximum stresses endured by the material under the worst of such conditions.

Chapter VI.—*Section I.* gives a structural description of the *fundamental* types of vessels known as 'Full Scantling' (one, two, and three deck), Spar-Decked, and Awning-Decked vessels; and modifications of these types.

Section II. describes the construction of typical vessels. Among these are:—The Royal Mail Steamers 'Campania' and 'Lucania'; the 'Great Eastern'; an Ocean Steamship Co.'s cargo steamer; 'Turret,' 'Trunk,' and other 'Self-Trimming' steamers; and, in addition, special arrangements for carrying water ballast for long over-sea voyages.

Chapter VII., which is the largest section of the book, deals in detail with the construction and combination generally of the various parts which go to make up the whole ship structure—framing, plating, stern frames and rudders, riveting, pumping, ventilation, etc., and includes also remarks upon launching.

Chapter VIII. describes the causes of decay and deterioration generally in a vessel, particularly noting those parts especially liable to rapid corrosion, and the best means of combating the causes of such corrosion, and of preserving and maintaining the structure in a state of efficiency.

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STEEL SHIPS.

CHAPTER I.

IRON AND STEEL.

Iron and Steel supersede Wood in Shipbuilding—Composition of Iron and Steel—Pig Iron, its Nature and Manufacture—The Blast Furnace—Castings—Malleable Cast Iron—Malleable or Wrought Iron; its Nature and Manufacture—The Puddling Furnace—Quality and Classification of Wrought Iron—Steel, its Nature and Composition—Siemens Steel, Manufacture of—Bessemer Steel, Manufacture of—Basic Steel—Cementation Steel—Case-hardened Steel—Crucible Steel—Steel Castings—Forgings—Iron and Steel Sections used in Shipbuilding.

Iron and Steel supersede Wood in Shipbuilding.—The day of wooden ships has practically gone. Travelling through our modern shipbuilding districts, one can scarcely fail to be struck by the conspicuous absence of this material. Whereas, sixty years ago, wood was the principal constructive element in shipbuilding, it is now a rare sight indeed to see in this country the hull of a seagoing craft being built of this material. Even then it is only used in the construction of the smallest types of vessels, or else only as a composite part of larger ones.

This great and rapid transformation has all been brought about by the introduction in shipbuilding, first of iron, and subsequently of steel. The manufacture of iron has been carried on for thousands of years, and great skill evinced in its production, while the uses of steel have been understood and appreciated for centuries. It is only since about the year 1860, however, that the latter could be produced in sufficient quantities and of the requisite quality for its adoption in the construction of ships. Even then it was not until after the year 1880 that steel became extensively employed in the building of ships for the mercantile marine. At the present time over 99 per cent. of the vessels built in this country are constructed of this material.

While, generally speaking, iron has given place to steel, it will be shown more definitely in a subsequent chapter that it still finds favour for certain purposes on account of important qualities which experience has shown it to possess. Hence, to a limited extent, it is still employed as a constructive element in certain parts of a ship.

It is in strength, toughness, and malleability, that steel, as now manufactured, shows its vast superiority over wood, and the possession of these qualities accounts for its having almost entirely superseded that material in the art of shipbuilding.

While the principal aim of this work is to describe the construction and the means which may be adopted for the maintenance or preservation of steel ships, it will not be out of place to convey some information respecting the process of the manufacture of steel, particularly noting those constituents of the metal whose presence or absence confers, in a marked degree, the qualities of malleability, ductility, weldability, hardness, softness, brittleness, toughness, cold-shortness and red-shortness and strength.

Although in a steamer the hull is principally composed of *mild* steel plates and bars, made by the Siemens process* (a process which takes its name from Sir William Siemens, the inventor of a system of producing steel which has proved especially suited to the requirements of ship construction), yet iron, in practically every form in which it is known commercially, is employed, to a greater or less extent, in the construction and equipment of a ship. We thus find, in addition to mild steel and steel castings, that iron castings, malleable iron plates, bars and forgings are also employed. The great bulk of plates and angles, bulb-plates and bulb-angles, tees, channels, and Z bars, etc., used in shipbuilding, are, however, made of Siemens steel.

To embrace the whole subject of the metallurgy of steel and iron in what must necessarily be a few pages in a work of this kind, would be an utter impossibility. However, notwithstanding the enormous dimensions of the subject, and the complicated processes attending the manufacture of iron and steel, we shall endeavour to convey to the reader unacquainted with the subject some knowledge of the manufacture, composition, etc., in as intelligible a manner as the brevity of the treatment will permit.

Composition of Iron and Steel.—As is well known, steel and iron are products of iron ore which is obtained, like all other minerals, from the earth by mining, and which, after being subjected to a course of treatment whereby most of the associated impurities are separated, yields iron or steel according to the nature and amount of the foreign elements still remaining in combination with the pure iron in the final product. There are many substances whose natures can be easily described by a simple definition. Such is not the case, however, with iron and steel as they occur commercially. Neither of them are pure metals. Indeed, absolutely pure iron, in addition to the practical impossibility of its production upon a large scale, is worthless for any industrial purpose. It is to the presence and proportions of the foreign elements or impurities which are introduced or found naturally in combination with the pure metal, that the special qualities which distinguish the alloys known as cast iron, malleable or wrought iron, and steel from each other, are really due. Iron ore, in its raw state, contains from about 30 to 70 per cent. of iron, according to the nature of the ore. Pig iron, the result of the first stage of the manufacture, contains from about 90 to 95 per cent. of pure iron; malleable or wrought iron over 99 per cent.; mild steel ship plates about 99½ per cent.; while other varieties of hard steel may contain considerably less of the pure metal, and a larger proportion of other elements. It will thus be seen that while neither iron nor steel are absolutely pure, the associated elements, whether metallic or non-metallic, are exceedingly small in proportion to the pure metal, and yet it is to the influence of these elements that the vast differences between cast iron, malleable iron, and steel, as to tenacity, ductility, and malleability, are attributable.

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* A small proportion of chequer plates, boiler plates, channels, etc., is still made from Bessemer steel. (See p. 14.)

The chief foreign elements found in commercial iron and steel are *carbon*, *sulphur*, *phosphorus*, *manganese*, and *silicon*, though infinitesimally small quantities of other substances may sometimes be present. Any one of the above substances, if in excess, may produce a deleterious influence, and confer an undesirable quality on the metal ultimately produced. The most important of these elements is *carbon*.

In *pig iron*, and likewise in cast iron, carbon is found in relatively large proportions, reaching sometimes to 5 per cent., and constituting, as a rule, not less than 3 per cent. of the total. Such metal may be hard and sometimes exceedingly brittle, or soft and tough, but these qualities depend less upon the amount of carbon present than upon the condition in which it occurs. Such iron readily melts at a high temperature, and can be moulded into various forms. In its crude form it is chiefly used in the production of malleable iron and steel.

Malleable or wrought iron may contain traces only of carbon, and at the most it rarely contains more than about ·12 per cent. At one time it was customary to define wrought iron as, chemically, the purest iron that could be produced for commercial purposes, but with the great improvements which have taken place in recent years in the manufacture of steel, it is outrivalled in this respect by mild steels produced in the processes introduced by Sir W. Siemens and Sir Henry Bessemer, so that the distinction between wrought iron and mild steel lies more in the mode of production than in chemical composition. Wrought iron is comparatively soft, malleable, ductile, and tenacious. It is excellently adapted for welding purposes, its malleability increasing as the temperature is increased. Fusion is only effected at very high temperatures. When heated and suddenly cooled it retains its softness. It may be produced direct from the ore, but is usually made from pig iron.

Mild Steel contains sometimes as little as ·06 to ·15 per cent. of carbon, along with small proportions of other elements. Such steel is malleable, ductile, and tenacious, and when low in carbon and comparatively free from other impurities, it is equal to wrought iron in its welding qualities. Siemens mild steel ship plates contain from ·12 to ·2 per cent.

(not more) of carbon. Steel containing over ·2 per cent. of carbon is not adapted for the manufacture of such plates, being too hard. The greater the proportion of carbon, the lower the temperature at which fusion occurs. Thus malleable iron requires a higher temperature for welding purposes than all except the very mildest qualities of steels.

A most important property of steel containing more than a certain percentage of carbon is that it is capable of being hardened or softened by the processes of tempering and annealing. In order to harden the metal, it is heated and suddenly cooled in oil or water, its final hardness depending largely upon the amount of carbon it contains. By reheating it and allowing it to cool slowly, almost any degree of softness required may be obtained.

Sulphur, even in infinitesimally small quantities, assumes, in combination with iron or steel, great importance. It is commonly found in iron ores, and combines with the metal on being subjected to heat. When present in excess it produces a most objectionable feature termed red-shortness. Such metal is useless for forging purposes, being defective in malleability, and when over ·12 per cent. of sulphur is present, it is 'rotten' at a red heat, and will, therefore, neither stand rolling nor hammering. Its presence in iron may result from using sulphurous ores, or it is introduced by the fuel employed in the blast furnace.* Small quantities of sulphur are supposed to be of some advantage in some kinds of castings, producing increased tensile strength, but for both malleable iron and steel plates and forgings the smaller the proportion present the better the metal. The commoner kinds of steel contain on an average ·05 to ·08 per cent. of sulphur.

Phosphorus, when present in iron to the amount of ·125 per cent., produces cold-shortness, that is to say, the metal is unable to withstand working and hammering at ordinary temperatures, owing to its reduced tenacity. It then cracks at the edges and breaks readily. Phosphorus unites readily with iron when subjected to a high temperature. It is present in most ores. When heated to redness, cold-shortness disappears, and the metal may be hammered or rolled with facility. When malleable iron or steel contains very small quantities of phosphorus, the metal is harder, while the tenacity may be scarcely affected. There are very few purposes for which more than ·1 per cent. is permissible, the tendency, where large proportions are present, being to reduce the tensile strength.

The effect of phosphorus may be modified by the presence and amount of other impurities. One advantage produced by a considerable proportion of phosphorus in cast iron is that it adds fluidity to the metal in a molten state, and is thus well adapted for very thin castings or for light ornamental work which has no stresses to bear; but for large heavy castings, where strength is required, such a metal would be very brittle and hence most unsuitable. Phosphorus is naturally found in greatest proportion in pig iron, but some grades, such as hematite, largely used in the manufacture of Siemens steel, contain very little.

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* The large furnaces in which the ores, fuel, and fluxes are treated preparatory to the production of *pig iron*. (See fig. 1.)

While phosphorus increases the tenacity of steel, its tendency to brittleness renders it less reliable in resisting sudden stresses caused by impact or shock. Mild steel plates for shipbuilding purposes usually contain from about ·04 to ·06 per cent. of phosphorus.

Manganese is always found in pig iron. Steel usually contains from ·2 to 1 per cent.,—ship plates, ·3 to ·6 per cent. Like carbon, it produces hardness, and increases the elasticity and tensile strength, but reduces the ductility. To some extent, manganese counteracts the red-shortness of sulphur, though, when itself in excess, it produces brittleness. It is most valuable as a neutralizing agent when such impurities as sulphur, phosphorus, silicon, etc., are present. When manganese is present in unusually large proportions in iron or steel, it is supposed to promote or hasten corrosion by sea-water. Specially prepared iron alloys, rich in manganese, and known as spiegeleisen, ferro-manganese, etc., are most valuable in the manufacture of mild steels, for the reasons already given.

Silicon is not an invariable constituent of steel. When present in considerable proportions it induces hardness, and also, like phosphorus, cold-shortness, which shows itself in the brittleness of the metal. At ordinary temperatures, such steel will neither stand rolling nor hammering. The usual percentage of silicon in steel is from about ·02 to ·06, with a limit of about ·08 per cent. Steel ship plates contain from ·03 to ·06 per cent. It is found in a greater or less degree in all ores. The higher the temperature the more readily does silicon combine with the metal. At a white heat, silicon is very liquid. Its greatest value is in foundry work. While iron comparatively free from silicon is hard and brittle, the introduction of a moderate proportion of specially prepared iron, rich in silicon, induces softness, strength, and fluidity. When the silicon is added in excess, it again produces hard, brittle, and weak castings, with reduced tensile and compressive strength. The result of an adjusted percentage of silicon is the production of sound castings remarkably free from blow-holes, and soft enough to be workable with tools.

Nickel is a metal whose presence is of the greatest value in steel for certain purposes, though its importance has only been established in comparatively recent years. It will doubtless be more extensively used in the future, especially in the manufacture of engine forgings and shafting. Like carbon, it increases the hardness and adds greatly to the tensile strength and toughness of the metal. These qualities are further improved by the process of tempering with subsequent annealing. For marine engines, where high speed combined with lightness and strength are the most desirable factors, nickel steel is being more and more used. For such forgings it is usually introduced in the proportion of from 3 to 5 per cent. For ordinary tramp steamers of low speed it is not as yet much used, the expensiveness of the metal being against its general adoption. Nickel is not a constituent in the composition of the steel employed for ship plates and bars.

The increased toughness of nickel steel makes it specially suitable for armour plates, as it offers great resistance to cracking by shock, or impact from shot, and also to perforation.

PIG IRON, CAST IRON, AND MALLEABLE IRON.

Pig Iron.—Pig iron differs from malleable iron and from steel in being unforgeable, and therefore unweldable; in its extremely low ductility; and chiefly in the large amount of impurities it contains.

Production. The Blast Furnace.—The actual smelting, or reduction of iron ore to a liquid state suitable for casting into the form of 'pig,' is effected in the blast furnace. The shape of these furnaces varies in different localities, as also do their heights, diameters, and capacities. In the Cleveland district in Yorkshire, where a very large proportion of the iron and steel used in shipbuilding in this country is manufactured, they have increased rapidly in size. Fig. 1 shows a Cleveland blast furnace. It consists of an outer shell of wrought iron plates riveted together, and resting upon a ring which is supported upon cast iron pillars. It is lined with fire-brick slabs, and closed at the top with a 'cup and cone' or 'bell-cone' arrangement. The waste gases are led away at the top of the furnace by means of a vertical pipe, or 'downcomer.' In some cases blast furnaces reach as much as 95 ft. in height. When the blast furnace is in full working order, or 'in blast,' it is filled to the top with a mixture of fuel, ore, and fluxes.

A flux is a material introduced into the blast furnace for the purpose of combining with the earthy matter attached to the ore,—much of which is otherwise almost infusible at the usual furnace temperatures. By this means a fusible substance known as slag is produced, which is one of the chief agents in carrying off the impurities. Thus, in order to effect the reduction of charges in which much silicon is contained in the ore, an abundance of limestone is generally introduced as a flux.

The furnace charges are always introduced at the top, additions being made frequently to keep the furnace full. These charges are taken up to a platform at the top of the furnace, and dropped on to the bell lid, which is so balanced as to sink beneath the superposed minerals. As soon as the material slides into the furnace, the lid rises again, and closes up the furnace mouth. The flare of flame so commonly seen at the summit of blast furnaces is caused by the escape of combustible gases whenever the bell is lowered. While the charge at the top of the blast furnace is thus composed entirely of solid matter, all the materials introduced pass away either in the form of gas, slag, or molten metal. The chief aid to combustion in the furnace is the introduction of a powerful air blast which may be hot or cold.*

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* As at present practised, these terms, hot and cold, must be regarded as relative. In hardly any case is the cold blast introduced without some preliminary heating.

This blast enters near the bottom of the furnace, and blows incessantly, excepting when fresh charges are being introduced into the furnace, and also during the time occupied in running out the molten metal, or, as it is called, 'tapping.'

The very high temperature produced in the blast furnace causes the molten iron to readily unite with a considerable amount of the carbon from the incandescent fuel in the furnace. The melted iron descends towards the base or hearth of the furnace, along with slags produced by the combination of the earthy substances in the ore with the fluxes. In its downward course the iron absorbs more carbon by contact, and finally accumulates in the hearth of the furnace, a compound of iron, carbon,

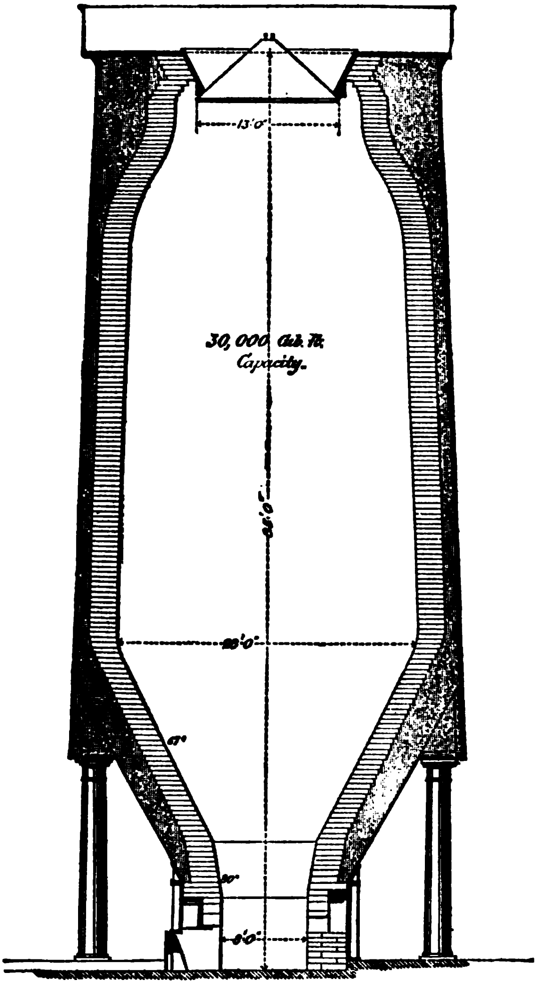
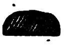


FIG. 1.—Section of a Cleveland Blast-Furnace.

sulphur, phosphorus, silicon, and other impurities. Owing to its greater specific gravity, the molten metal sinks to the bottom and the slag floats on the top. The passage of the blast into the furnace near the bottom, laden as it is with oxygen, would decarburize the metal, were it not for the protecting influence of the slag floating above it. As the slag continues to increase on the surface of the steadily accumulating metal, it at last reaches a height where there is an aperture in the furnace side (the slag notch), out of which it flows. By a variety of means it is collected, and taken away at intervals. The process of smelting in the blast furnace results in the production of highly carburized metal.

The more phosphorus the ore contains, the greater the proportion which passes into the slag. However, many ores contain less than 1 per cent., and then it practically all passes into the iron. If manganese be a constituent of the ore, which is generally the case, it is found partly in the pig iron, and partly in the slag. Pig iron containing about 5 per cent. of manganese and upwards is called spiegeleisen, but when above 40 per cent. is present, it is known as ferro-manganese. This is largely used in the subsequent manufacture of mild steel. Sulphur is to a considerable extent eliminated in the preliminary process of calcination.* However, a quantity may still find its way from the ore and fuel into the product. As silicon is only reduced at the very highest furnace temperatures, a comparatively small proportion only of the total passes into the metal, the greater proportion passing into the slag. It follows, therefore, that a more siliceous metal is produced from hot-blast than in cold-blast furnaces. By means of a basic slag (one rich in lime), silicon is still further eliminated. Highly siliceous iron, which has special uses in foundry work, is only produced at the expense of a large expenditure of fuel and at a high temperature.

The richer the ore, the less limestone is necessary in the charge, and, consequently, less slag is produced, and the fuel consumption is smaller.

The blocks of metal called pigs, of  section, and about 3 ft. in length, are obtained by preparing a damp bed of sand in front of the furnace, in which grooves are made by wooden 'patterns' corresponding to the shape of the pigs. By means of a channel in the sand the molten metal is led from the furnace to these grooves.

Castings.—While pig iron is extensively used in the manufacture of wrought iron and steel, a large quantity is also used in the production of castings in the foundry.

Though rolled iron and steel preponderate as the constructive elements in modern ships, still, a survey of any vessel will reveal many fittings made of cast iron—bollards or mooring bits, hawsepipes, boat-davit sockets,

[*] Calcination is a process of roasting to which certain kinds of ores are subjected, by which means, combined with the effect of the atmosphere, water, sulphur, carbonic acid, and other volatile matters are wholly or in part driven off.

fair leaders, the columns supporting engines, cylinders, and many other fittings on the hull and in the engine room. In smelting pig iron for castings, special care is required in selecting and combining the most suitable brands or grades.

Several reasons may be given for the extensive use of cast iron. It can be melted at a comparatively low temperature as compared to that required in working the metal in some of its other forms. It is the cheapest form in which iron is produced. Iron is specially adapted for castings, being very fluid and capable of receiving clear, definite, and exact impressions from the mould. It possesses enormous crushing strength. The tensile strength of cast iron varies from about 5 to 15 tons per square inch of section, the average of good cast iron being about 8 tons. The transverse and torsional strength varies between 1·5 and 4·5 tons per square inch. Its average shearing strength is about 12 tons to the square inch. The crushing strength of ordinary cast iron lies between 25 and 60 tons; the average being from about 40 to 45 tons. The tensile strength averages about one-sixth of the crushing strength. It will thus be clear that while cast iron is admirably adapted by its great strength under a compressive stress for such purposes as columns and struts, it is totally unfit for use where sudden and severe torsional, tensional, or transverse stresses, such as experienced by the hulls of ships, have to be borne.

As already stated, cast iron is superior to wrought iron for compressive, but greatly inferior for tensional stresses. It is therefore unfit for ship-hold stanchions or pillars which have to act both as *struts* and *ties*.

In choosing pig iron for castings, it is necessary to take into account the nature of the casting and the purpose for which it is required. There will thus be a vast difference in the quality of pig iron used for engine cylinders, machinery, girders for structural purposes, etc., and that required for light ornamental work. For the latter, fluidity would be an important quality, and thus phosphorus and silicon would be welcome constituents of the metal. But phosphorus, when in excess, produces brittleness, cold-shortness, and weak castings, and therefore while this feature would make no practical difference in the ornamental castings, it would be an objectionable constituent in iron for structural purposes, where severe, and, probably, sudden stresses would be experienced.

In remelting pig iron for important castings, it is the practice to combine iron of several grades, and by this means a stronger metal is obtained, the aim generally being to get a compact grey iron. The metal may be further increased in strength and toughness by melting with it either wrought iron or steel scrap. A most important element in the production of good castings is silicon, when not present in quantities exceeding 2·5 per cent. Its value in foundry work has already been described on page 5. Remelting soft cast iron makes it harder and stronger, but remelting hard iron makes it harder and more brittle, weak, and unworkable with tools.

Malleable Cast Iron.—Castings made from pig iron are both hard and brittle, and are workable with neither file nor chisel. This may be remedied by a process somewhat resembling annealing, and by means of which the metal is made to approximate more to malleable iron. The castings are embedded in powdered red hematite in cast iron 'boxes' and placed in furnaces. In the operation which follows, silicon, sulphur, manganese and carbon are removed from the surfaces. Such castings are capable of being, to some degree, forged and chiselled, and are rendered soft, tougher, and stronger, though they are incapable of being welded. This process is sometimes applied to machinery and propellers, rendering the latter especially less liable to breakage by blows or accidents. In large castings, only the outer surface is affected by this treatment, hence the necessity of choosing pig iron as free as possible from phosphorus, sulphur, silicon and manganese.

Malleable or Wrought Iron.—The distinctive features of malleable or wrought iron used to be its small percentage of carbon and its almost complete freedom from phosphorus, sulphur, silicon, and other foreign elements. But with the vast improvements which have been made in the production of mild steel in recent times, the special qualities of malleable iron, viz., malleability, ductility, weldability, and tensile strength, are found to an almost equal extent in mild steel.

Considerable difficulty, therefore, presents itself in attempting to define the difference between malleable iron and mild steel. The difference, as was stated on an earlier page, must be attributable to the actual method of production, malleable iron being the term applied to the production of iron chiefly by the process of puddling. A distinct difference between wrought iron, cast iron and cast steel is, that while the former is fibrous, the two latter are not, but present granular appearances, when fractured. Cast iron, moreover, is hard and brittle when cold, while wrought iron is soft and ductile. It differs from the harder kinds of steel in the fact that it does not temper well, *i.e.* if heated in a furnace and plunged into water or oil, it shows little sign of hardening. This is a distinct characteristic of hard steels, though mild steels, such as ship plates, resemble wrought iron in being practically incapable of being tempered. It is scarcely necessary to add that only iron in its malleable form can be of use to the ship's smith.

Malleable iron is obtained indirectly from pig iron by '*puddling*,' whereby most of the impurities are got rid of, and the metal is delivered from the puddling furnace in a pasty condition, ready to be hammered and rolled into the required sections or shapes.

Production. Puddling Furnaces.—What is known as the ordinary single puddling furnace is a long horizontal furnace at one end of which is the fire and at the other end the flue from whence the smoke and heat escape to the chimney, or else are economized by being led away for reheating purposes. Between the fire and the flue is the puddling bed, upon which the charge is laid, being introduced through an opening in the side of the furnace. In this system the pig iron is charged into the bed of the furnace entirely away from the fire grate upon which the fuel is consumed, but in such a position as to be exposed to the action of the flame and draught. After the charge has been made and the fire replenished, the furnace is entirely closed. In a short time the metal begins to soften, and the puddler then introduces a long iron bar through an opening in the charging door, and 'puddles' or turns over, or works the pigs so that they are uniformly heated.

Ultimately the iron is reduced to a more or less fluid state, and spreads itself out over the furnace bed, where it is stirred in order to expose it uniformly to the action of the heat. After this operation has been continued, so that the carbon of the iron has been more or less eliminated by the influence of the oxidizing atmosphere passing through the furnace, the iron begins to stiffen, and spongy masses of malleable metal begin to appear amongst the slag, which has gathered on the surface of the fluid metal. The puddler works up the spongy masses of iron into balls, weighing about 60 or 80 lbs., by means of his iron bar. When these have been made, and are sufficiently coherent, the balls are drawn out of the furnace separately, and carried to the forge hammer, where they are 'shingled' or hammered. This operation again rids the iron of much impurity, which is seen to fly out as slag, with every blow of the hammer. When the iron has been formed into a consolidated block, or 'bloom,' it is taken to the rolls, where it is rolled into lengths of bar iron. In the several phases through which the metal passes between entering and leaving the furnace, silicon, manganese, phosphorus, carbon, etc., are all more or less eliminated.

Quality and Classification.—The quality and grade of the iron is largely determined by the subsequent mechanical treatment it receives. Thus the long length of rolled bar made from the bloom is termed No. 1 quality, or merchant bar. To obtain ordinary malleable iron of No. 2 quality suitable for smiths' use, No. 1 quality is cut up into short lengths, arranged into piles, and placed in a reheating furnace, from which it is taken and again rolled. To obtain No. 3, or best iron, a pile of iron is again formed for reheating. It may consist entirely of short lengths of No. 2, or of No. 1 with the top and bottom plates only of No. 2, and after reheating, is again passed through the rolls. This quality is known as best merchant iron, or treble best, and is admirably adapted for welding, possessing the qualities of toughness and ductility in a more marked degree than any of the lower grades. Ordinary ship-hold stanchions, or pillars, are usually made of No. 2 quality.*

Just as repeatedly remelting cast iron may, in the earlier stages, improve the metal, but ultimately produce weak and brittle castings, so on reheating wrought iron the strength and ductility of the metal is improved by the first few operations. Yet when the reheatings exceed five or six times, the metal shows distinct deterioration in quality. Hence, for ordinary purposes, one reheating after the puddled bar has been cut up is found sufficient, and when the iron is for smiths' use, the subsequent reheatings tend to the further improvement of the metal. Best best iron is specially suitable for anchors, chains, cables, rivets, etc.

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* The names vary greatly in different districts. Thus, in some, No. 1 is known as best, No. 2 as best best, and No. 3 as treble best.

For the production of iron plates for ships' use, a similar method of piling is employed. A pile is formed by placing the lengths of bars in alternate layers—the bars in one layer being placed across the bars of the layer beneath, the top and bottom being covered by a simple thick slab suitable for the dimensions of the plate it is intended to produce. In a like manner, in order to produce iron tee bars, butterly bulbs, and girder sections used in shipbuilding, the operation of piling is carried out. Special care is required in the building of these piles, for unless the butt or end joints of the bars in the pile be well covered by the next layer, they do not weld properly. Thus it is customary in building the piles for the sections of iron just mentioned, to make the top and bottom flanges of these sections of a single slab of iron usually of a superior quality to the bars used in the centre of the piles.

The quality of the iron produced depends not only upon the quality of the pig iron first charged into the puddling furnace, but also upon the manipulation of the furnace in regulating the heat and gases. The production of either very soft, or hard, or steely iron, or of iron lacking in tenacity, is due to a considerable extent to the skill or otherwise of the puddler. The more impurity the iron contains, the longer does it take to carry out the puddling operation, and there is, in consequence, a greater waste of metal.

It need scarcely be repeated that the aim of puddling is to almost eliminate carbon, phosphorus, sulphur, silicon, manganese, and other impurities. To such an extent is this effected in good wrought iron, that the finished metal contains over 99·5 per cent. of pure metal, sometimes quite as much as 99·7, with usually only a trace of carbon,* and correspondingly small proportions of the other elements mentioned. To absolutely purify the metal and produce pure iron is not desired, and, moreover, such a product would be commercially worthless.

The conversion of bar iron into the required sections for shipbuilding and other uses is effected by rolling in cast iron rolls, which are specially cast and 'turned' to suit the numerous sections of iron required.

Steel.—*Nature and Composition.*—Considerable difficulty attends the attempt to accurately define the milder kinds of steel, as distinct from malleable iron. Malleable iron, as we have seen, is delivered from the furnace in a soft, spongy state. Steel, however, is delivered in a state of fusion, the metal being cast directly from the furnace into a mould, thus forming a malleable ingot of sufficient weight to produce the bars or plates required. Cast iron is also delivered from the furnace in a state of fusion, but it differs from steel in its total lack of malleability and ductility.

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* The purest iron, sometimes termed piano wire quality, will, at times, contain as much as 99·85 per cent. of pure iron.

An absolute essential in steel is carbon, though it may be present in exceedingly small quantities, ranging from ·06 to 1·5 per cent. For Siemens steel ship plates the percentage is from about ·09 to ·14. While phosphorus, sulphur, silicon, manganese, etc., may also be present, they are all looked upon as impurities, though, under certain conditions, the presence of some of them, in small proportions, may exercise a beneficial, or at least a non-injurious effect upon the steel. An idea of the composition of Siemens steel ship plates will be obtained from the following figures.

Siemens Steel Plates.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
	·09 to ·14	·03 to ·06	·04 to ·06	·04 to ·06	·30 to ·60

Mild steel is both malleable and forgeable at a full red heat, but owing to the percentage of carbon present, it should be worked at a lower temperature than wrought iron, except in the harder qualities, there being a danger of 'burning' the metal. As previously stated, the property of tempering is possessed only by the harder kinds of steels. Malleable iron is not affected by such treatment, and mild steel, with its small percentage of carbon, is incapable of being tempered to any marked degree. The hardness produced by tempering is in proportion to the carbon in the steel, and the rapidity with which it is cooled. If steel be too much heated, it is said to be burnt, and becomes unweldable.

Steel, in a greater or less degree, unites the qualities of cast and malleable iron. It may be produced in a number of ways, although ship plates and bars are almost exclusively manufactured by the Siemens process.

Siemens Steel.—The success which has attended the manufacture of mild steel by the Siemens process, has given it an unrivalled importance for the purposes of shipbuilding. The principal feature in the production of Siemens steel, lies in the reduction and treatment of pig iron and selected ores in what is known as the Siemens open hearth furnace.

This gave rise to a modification of the process, whereby steel was produced by first melting pig iron in the hearth of the Siemens furnace, and then charging into this bath, wrought iron in the form of scrap, croppings, etc. This process was ultimately known as the Siemens-Martin process.

The Siemens open hearth process, as now practised and generally adopted in this country, consists practically of a combination of the two fore-mentioned methods. Suitable pig iron is first charged into the hearth of the furnace and reduced to a liquid state. Into this, scrap metal from the rolling mills and iron ore of good quality are introduced. Finally, when the metal in the furnace has reached the necessary degree of purification, it is found that it has become almost completely decarburized, that is, the action of the furnace has eliminated the carbon, and it is necessary that this essential element, together with a proportion of manganese, should be restored. Hence, spiegeleisen, or ferro-manganese, both of which are rich in carbon and manganese, are charged into the furnace just before the conclusion of the process.

When the metal is ready to be discharged from the furnace, it is tapped into a ladle, and cast from thence into moulds, usually of cast iron. These castings are known as ingots. In order to convert them into plates or bars of any particular section, they have to be rolled. If the ingots were exposed to the air and allowed to cool they would solidify, but the solidifying operation would not go on uniformly throughout the ingot, as obviously the outside would cool and 'set' more rapidly than the interior. It therefore becomes necessary to either place the ingots in pits specially heated, in which they can come to the solid state suitable for rolling purposes, with a uniform temperature; or else they are allowed to cool, and are reheated in a special furnace. The ingots are, in either case, taken to the mills, and finally finished by rolling into whatever sections (plates, bars, etc.) may be required. Charges amounting to from 30 to 50 tons may be melted in the Siemens open hearth furnace at once, and in America even larger charges are worked.

Siemens steel is more uniform in quality than that obtained by the Bessemer process, and it is largely owing to this fact that it has become so universally adopted for ship construction. Mild Siemens steel for ship plates and bars possesses a tensile strength averaging 30 tons. It is also very ductile, showing an elongation of at least 20 per cent. in a length of 8 in., and is as malleable as wrought iron. The Siemens process is specially suitable for the manufacture of steel for castings.

Bessemer Process.—In the early days of steel ships, Bessemer steel (named after Sir Henry Bessemer, the inventor of the process of manufacture) was to some extent employed, though now it has almost entirely given place to Siemens steel. It is, however, extensively used, and admirably adapted for the manufacture of rails. The process is conducted in a pear-shaped vessel, called a converter, which, in the system most widely adopted, is swung upon an axis, and can be tilted at any angle. This arrangement greatly facilitates the work of discharging the metal from the mouth of the converter.

Bessemer steel is produced from pig iron which is conveyed in a molten state direct from the blast furnace in a huge ladle, and charged into the converter.

The predominant feature in this system is, that the pig iron is decarburized, *i.e.* purified to a greater or less degree from its over-supply of carbon by the action of the oxygen of the air, which is blown from the bottom of the converter through the fluid metal. By this means the greater part of the carbon, silicon, and manganese of the pig iron are oxidized and consumed.

The passage of the air blasts through the molten metal causes violent ebullition, owing to the escape of carbonic oxide resulting from the oxidation of the carbon in the pig iron and the oxygen of the blast, combined with the intense heat developed. By the nature of the flame it can be judged when the operation of blowing has been carried on sufficiently, that is, when the almost complete decarburization of the metal has been attained.

Towards the conclusion of the 'blow' in the Bessemer converter, a metal would be produced practically free from carbon, silicon, and manganese, but still containing any sulphur or phosphorus which was present in the original metal. Such a metal would be exceedingly soft and unweldable, and probably both red-short and cold-short, so that when rolled it would crack round the edges, and even crumble to pieces. It therefore becomes necessary, just before the termination of the blow, to furnish the metal in the converter with the necessary proportion of carbon and manganese in the form of spiegeleisen, or ferro-manganese, the manganese counteracting the effect of the sulphur and to a less degree neutralizing the effect of phosphorus. When the metal is finally ready for discharging from the converter, it is cast into ingots in a way similar to that described for Siemens steel.

When the metal is overblown, it is burnt, and possesses the quality known as 'rottenness.'

Basic Steel.—The method known as the 'Basic' process of producing steel may be conducted in either the ordinary Siemens open hearth furnaces, or in Bessemer converters, usually the former. The modification in the furnace for the Basic process lies chiefly in the nature of the lining, which is made of dolomite or magnesian limestone. During the working of the charge of pig iron, a considerable quantity of limestone is introduced into the furnace. This combines with the silicon and phosphorus, and passes off in the form of slag. By this means, phosphoric ores, which would otherwise be unsuited for the manufacture of steel, can be employed.

The principle of the Siemens open hearth and of the Bessemer process is practically identical in each case. The molten metal is first decarburized, and then, by the addition of spiegeleisen, or ferro-manganese, it is recarburized to the desired extent. It is decarburized, because of the difficulty of ascertaining the precise amount of the impurities present. Then the foreign ingredients are added, in the proportions found by experience to be necessary.

While steel of good quality may be produced by either of these processes, Siemens steel is more uniform in quality, and better meets shipbuilding requirements. The Bessemer process is admirably adapted for the manufacture of rails, *but mild steel for ship plates and bars is made almost exclusively by the Siemens process.*

Cementation Steel, Case-hardened Steel, and Crucible Steel.—As cementation steel and case-hardened steel do not play any part in the construction of the hulls of merchant ships, a very brief description of these processes must suffice in passing. ('Harveyized' and kindred hard steels, used particularly for armour plating in war vessels, may, however, be regarded as forms of 'case-hardened' steel).

In producing steel by the cementation process, bars of malleable iron are embedded in charcoal and placed in a furnace, where a high and long-continued temperature is maintained. By this means the carbon of the charcoal permeates the malleable iron. By a somewhat similar process, known as case-hardening, carried out at a great heat, a thin layer of steel may be produced upon the outside of the iron. When a hard surface is required over part of the steel, the tempering is done by immersing such parts in cold water or oil after reheating, or, in order to harden the whole surface, the steel is totally immersed in water. The interior of the case-hardened metal remains wrought iron. Where, however, the process of cementation is long-continued, the entire bar of malleable iron may be converted into steel. A peculiarity of the process of cementation is the blistering of the surface of the metal bars, hence this kind of steel is known as 'blister steel.'

The bars are ultimately cut up into short lengths, subjected to one or more reheatings in piles, welded by hammering, and rolled. By this treatment the qualities of tenacity and strength are considerably improved. The best quality of steel, however, can only be obtained by breaking up the blister steel and melting it in a crucible or pot. This renders it more uniform in its nature. It is then called crucible steel, and is the most valuable steel produced. It is chiefly used for tools, cutlery, and also for special forgings and castings.

Steel Castings.—On examining steel ingots, we invariably find that they are honeycombed with cavities or holes, probably owing to the escape of gas. This would naturally be a most detrimental feature in important steel castings. Various devices have been proposed to overcome these defects, but probably the introduction of silicon is one of the simplest and most effective. By this means, it would appear that the formation of such cavities and unsoundness is prevented.

We have seen, however, that silicon in large proportions exerts a detrimental influence on the steel produced, reducing its malleability, ductility, and tensile strength, as well as its adaptability for being hammered. It therefore becomes necessary to somewhat counteract the effect of the silicon, and thus manganese is introduced also.

The combined silicon and manganese is called silico-spiegel, and is introduced into the molten metal just before the operation of casting. Siemens steel is also used for castings.

Steel castings should be annealed, that is, they should be heated to a red heat, and then allowed to cool down slowly, generally embedded in ashes or other substance, which will make the cooling process gradual. This operation renders the casting softer in its nature, and more uniform in strength. Cast steel stern frames are now commonly employed, though some difference of opinion exists as to whether they are preferable to wrought iron forgings.

Forgings.—Among the moving parts of the engines, and also in the hulls of steamers, we find numerous forgings (crank shafts, stern frames, etc.), which were at one time made exclusively of wrought iron, but are now commonly made of steel. The excellent welding properties of wrought iron make it possible for most satisfactory results to be obtained in the production of large forgings, by the process of welding together the several pieces which go to make up the whole structure.

In very large and heavy wrought iron forgings, however, there is always the possible danger of unsatisfactory welding, which, moreover, may not be very apparent on the surface, and only fully revealed after the forging has fractured, owing to severe stresses.

In the case of mild steel forgings, the operation of 'forging' consists purely in the rolling and compression to which the steel is subjected; and the metal from which crank shafts, etc., are made, is practically identical with that of any other mill products, such as angles, tees, etc. Honeycombing is eliminated in the rolling and under the steam hammer. As a matter of fact, the lower the percentage of carbon the less homogeneous the steel. Very 'hollow' ingots usually result when the carbon falls below ·07 per cent. Nevertheless, as long as such ingots can be rolled at all, the resulting finished bar will be sound. It is not possible to roll a shaft with cranks at various angles. Large shafts are built up; the parts being shrunk on and keyed. Crucible steel is unsuitable, owing to the small quantities produced at a time, for anything but the smallest castings, and is not used to any great extent for ship work.

In important steel forgings the qualities of tensile strength and toughness are further improved by tempering in oil with subsequent annealing, and the thinner the section of the forging, the greater the tempering effect. Hence the advantage, in such forgings as propeller shafts, of having a hole through the centre, as this not only reduces the weight of the forging, by removing that part of the material in the shaft which contributes least in affording strength, but facilitates and improves the results of tempering. It may be noted that shafts are often cast hollow.

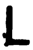
The qualities of forgings have been still further improved by introducing other metals in combination with steel, notably nickel, which produces a remarkable improvement both in the tensile strength and elastic limit of steel (see page 21), and also increased power to resist fracture by impact or shock. Nickel also adds to the efficiency of tempering.

Wrought iron forgings which have been built up by welding several pieces together, should always be annealed, for otherwise there may be considerable irregularity in the strength, owing to variation in the heats and irregularity in cooling.

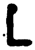
IRON AND STEEL SECTIONS USED IN SHIPBUILDING.

The following is a list of the principal sections of steel and iron which are rolled in the 'mills,' and are suitable for the construction of ships.

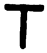
1. *Plain plates*, used for shell, decks, tanks, stringers, bulkheads, etc.
2. *Chequer plates*, for decks, platforms, etc.



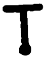
3. *Plain angle bars*, used for frames, reversed frames, beams, stringers, keelsons, bulkhead stiffeners, and for connections in every part of the vessel.



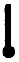
4. *Bulb angles*. These may be used for frames, beams, bulkhead stiffeners, keelsons, stringers, etc.



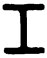
5. *Plain tee bars*, used for beams, stiffeners, stanchions, etc.



6. *Butterly bulbs* or *tee bulbs*, used chiefly for beams and hold stringers.

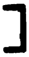


7. *Bulb plates*, used in conjunction with angles for beams, keelsons, stringers, stiffeners, etc.



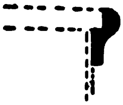
8. *H bars* or girders, used for strong beams and keelsons.

9. *Z bars*, used for frames and bulkhead stiffeners.

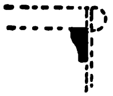


10. *Channel bars*, for frames, beams, bulkhead stiffeners and stanchions

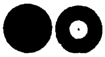
11. *Half round*, *convex iron*, and *flat bar*, for mouldings and sometimes for stiffeners of casings in passage-ways where sharp angle stiffeners might be dangerous.



12. *A patent section for hatches*, combining in efficiency both the usual rest iron for hatch covers and moulding.



13. *Rest iron*, which is attached to the inside of hatch coamings to support the covers.



14. *Round iron*, for pillars, stanchions, etc. This may be solid or hollow.

CHAPTER II.

STRENGTH, QUALITY, AND TESTS OF STEEL FOR SHIPBUILDING PURPOSES.

Definitions of Important Terms; Tensile Strength, Stress, Ductility, Elasticity, Elastic Limit—Value of Nickel—Fatigue—Tests of Plates and Angles—Remarks upon the Reduction in Thickness of Steel Plates—Tests for Steel Castings—Rivet Tests—Treatment of Plates and Bars in Shipyard.

Definitions of Important Terms.—Having briefly traversed the steps in the process of the manufacture, and noted the constituents of iron and steel it is now proposed to inquire into the special qualities essential for purposes of ship construction, and the tests to which the metal is subjected in order to ensure the possession of such qualities.

It is advisable at this stage to clearly understand certain terms and expressions which are constantly recurring in treating this aspect of the subject.

Tensile Strength.—By the *tenacity* of steel is meant the property of adhesion, and the *tensile strength* is the measure of the greatest stretching force, applied in the direction of the length of the material, necessary to produce fracture; or, in other words, it is equivalent to the maximum stress required to produce fracture, and is usually expressed by the number of tons required to break a bar one square inch in sectional area. The remarkable tenacity of steel is one of its most valuable and important characteristics.

Stress may be defined as the resistance offered by any material to deformation caused by the application of an external force. Stress is also equal to the intensity of the force which produces deformation, providing that it is not so great as to cause rupture or fracture (see also page 75, Chapter V. on 'Stress and Strength').

Ductility is the property of being permanently elongated by the application of a tensile force. This property in steel is well illustrated by the fact that it can be drawn into wire.

Elasticity and Elastic Limit.—Within certain limits, if a tensile force be applied to a bar of steel, it will show distinct elongation, but immediately upon the removal of this stretching force the material returns to its original dimensions.

This elastic quality is termed *elasticity*. Elasticity may also be defined as that property whereby, after the metal has been subject to a certain pressure, whether of tension or compression, at a given temperature, it seeks to regain and retain its original volume and shape. If steel, however, be stressed beyond this limit, permanent elongation, or '*set*,' takes place. This limit, or point, at which elasticity ceases, and permanent set or distortion takes place, is called the '*elastic limit*.' The elastic strength is thus the tensile strength up to the elastic limit. So long as steel is not subject to a stress beyond the elastic limit, the elongation is directly proportional to the stress, but as soon as the elastic limit is passed, the elongation takes place at a more rapid rate. It will now be clear that in very ductile materials, such as wrought iron and mild steel, very considerable distortion and elongation beyond the elastic limit may occur before actual fracture takes place.

Most of the harder steels possess less ductility, though their elastic limit and ultimate tensile strength may be greater. It is obvious to everyone how important these qualities of tenacity, ductility, and elasticity must be in such a structure as a ship. In a large iron or steel vessel rolling and pitching in a seaway, enormous and innumerable stresses are set up in every part of the structure, and owing to the elasticity of the material, though imperceptible to ordinary observation, there is a certain amount of give and take—elongation and retraction—constantly going on, which must somewhat relieve the severity of the stresses which are experienced by rivets and connections generally. True, this is not, nor should it be, so serious as to be perceptible, nevertheless, knowing what we do of the numerous stresses borne by ships at sea, and also of the elastic quality of iron and steel, it follows that this actually takes place to a greater or less degree.

The value of ductility in steel is often manifested in cases of collision, or fouling, or grounding. Steel plates, in such cases, have been known to buckle and bend, and to be greatly twisted and distorted, and yet show no signs whatever of rupture.

Importance of Elastic Limit.—In considering the strength of steel for ship construction, important as tensile strength may be, the elastic limit is of still greater importance. In fact, in dealing with structures from a purely strength point of view, it is the elastic limit and not tensile strength which is of foremost consideration. And while ductility is of great importance, and it might be possible to stretch the steel in a ship considerably beyond the elastic limit but well within the tensile strength, such permanent elongation, excepting under such exceptional circumstances as grounding, collision, etc., is decidedly most objectionable, and could only be productive of ultimate disaster. It can easily be imagined what horrible distortion in the form of a steel ship would ensue, if vessels were built to anything approaching their maximum tensile strength, or even in such a way as to be subject to stresses in excess of the elastic limit.

Thus the aim of the designer of ships, bridges, etc., after obtaining all other necessary qualities and properties, is to get the maximum limit of elasticity in the material required for the structure in question.

Nickel.—In recent years, considerable improvement has been made in the manufacture of steel forgings for marine engines and also for boiler tubes, by introducing suitable proportions of nickel during the process of manufacture. This has the effect of increasing both the tensile strength and the elastic limit. But as nickel induces hardness, and is also very costly, it is not used in the manufacture of steel for ship plates and bars. Nickel in boiler tubes has been found to retard corrosion.

The tensile strength, ductility, and elasticity of steel are further increased by elongation, produced by cold rolling and wire-drawing at suitable temperatures. This is amply illustrated in the case of steel wire. Steel rods drawn into wire will increase as much as 80 to 100 per cent. and over, in tensile strength. So that steel wire with a tensile strength of 100 tons per square inch is a common production, while even this has been greatly exceeded.

Fatigue.—Of course, it is clearly understood that where elongation of the nature just described is carried out, the stretching force is applied most gradually. Suddenly applied irregular stresses, which vary greatly in magnitude, produce what is known as *Fatigue*, that is, diminished resistance to rupture. This probably accounts for the fracturing of tail-end shafts, which experience severe jerking strains as the propeller blades strike the water after emersion in pitching movements. A similar reason could be found for many other breakages. Such irregular strains undoubtedly cause disarrangement in the natural molecular disposition in both iron and steel, and microscopic examinations of such fractures show the effects of this disturbance.

In ordinary mild ship plate steel the elastic limit ranges at about 50 per cent. of the tensile strength. Tempered nickel steel may even have a tensile strength of 45 tons and over, with an elastic limit of 30 tons, while hard drawn steel wire may reach an elastic limit of 50 tons.

Tests.—Classification Societies such as Lloyd's, Bureau Veritas, and the British Corporation, agree very closely as to the qualities of iron and steel for shipbuilding purposes, and consequently their tests are generally very similar. Samples of the steel are tested at the steel works (under the personal inspection of the society's surveyors) before the material leaves for the premises of the shipbuilder. These societies require that samples be tested from every charge or cast employed in the manufacture of the material; and moreover, that the whole operation and process of testing be witnessed by their surveyors. If they are satisfied with the manner in which the steel stands the various tests imposed upon it, then every plate, beam, and angle is required to be clearly and distinctly stamped by the manufacturer. The brand upon the steel so tested is as follows:

LR (Lloyd's).   **B.C.** British Corporation.

and indicates that a shearing from the plate or bar has satisfactorily passed through the whole of the tests made upon it.

When these samples fail to fulfil the test requirements, the plates or angles from which they were cut are rejected. These tests are made so as to ascertain and measure the tenacity or tensile strength of the steel, its ductility and elasticity, and also its transverse or bending strength. Such tests usually comprise hot and cold forge tests, tempering, and, in the case of forgings, the sudden impact caused by either allowing the forging to fall on hard ground, or by dropping weights upon the forging. In testing steel, the classification societies require that strips from a plate, angle, or bulb plate or bar, cut lengthwise or crosswise, should have an ultimate tensile strength of not less than 28 and not exceeding 32 tons per square inch of section, with an elongation equal to at least 20 per cent. on a length of 8 in. before fracture in samples $\frac{8}{20}$ths of an inch and above in thickness, and 16 per cent. in samples below this thickness. The elongation test, it is scarcely necessary to add, is to ensure ductility, and the limit of 32 tons as the maximum tensile strength is to obtain a metal which is soft, and as workable in the hands of ships' platers and smiths as the best wrought iron. Indeed, where sharp bends are required, as in garboard strakes for bar keels, and in the plates round the stem and counter and stern frame (boss and oxter plates), steel is greatly to be preferred to wrought iron, as it can be manipulated with better results.

So easily can steel plates be bent, that it is now a very common practice with shipbuilders to make the corners of engine and boiler casings and deckhouses with a single plate bent to a radius of 2, 3, or more inches, thus dispensing with the usual connecting corner angle bar. Steel plates are also preferable for the round corners of hatch coamings. So fully recognized is this quality in steel, that even where iron is employed for houses on deck, etc., it is a very common practice for shipbuilders to adopt steel plates for the bends at the corners, etc.

Classification societies also require that steel angles for the frames of vessels, and bulb steel for beams, may have a maximum tensile strength of as much as 33 tons per square inch of section.

Strips cut from the plate, angle, or bulb steel, after being heated to a low cherry red, and cooled in water of 82° Fahr., must stand bending double round a curve of which the diameter is not more than three times the thickness of the plate tested. In addition, samples of plates and bars should be subjected to cold bending tests.

Among the numerous tests adopted, the following may be taken as examples.

Mild steel cut into strips of about 1½ in. in width, should stand being bent cold in a hydraulic press to a curve the diameter of which does not exceed twice the thickness of the plate (or inner radius of bend equal to thickness of plate). (See fig. 2.)

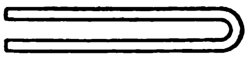


Fig. 2.—Cold Bending Test.

A plain angle should bend hot as shown in Nos. 2 and 3, fig. 3.

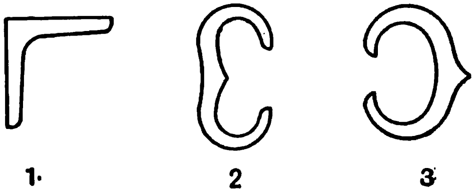


FIG. 3.—Hot Angle Tests.

A T bar should bend hot as shown in Nos. 2 and 3, fig. 4.

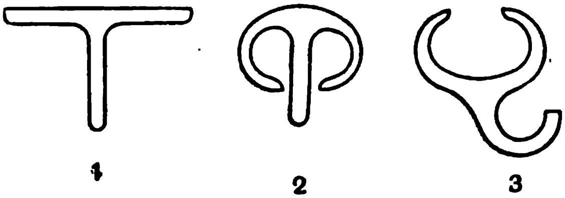


FIG. 4.—Hot Tee Bar Tests.

Turning to wrought iron, we find that the classification societies require that, for vessels classed by them, it must be of good malleable quality, capable of standing a tensile strain of 20 tons per square inch with, and 18 tons across, the grain, and of standing certain hot and cold forge tests.*

Remarks upon the Reduction in Thickness of Steel Plates.

The advantage of mild steel over wrought iron is at once apparent. The tensile strength is increased from 40 to 50 per cent., while the metal shows very decided superiority in elasticity and ductility. As a natural result, steel ships are lighter in weight than iron ones, a reduction of about 20 per cent. being usually allowed by the classification societies in the thickness of steel plates and angles, and as a more lightly constructed ship permits of a greater deadweight being carried, and thus increased freights being earned, the reason for the universal adoption of steel is obvious, and more especially as the price of steel is usually as low as that of iron. But even with so much to recommend it, there are still certain minor disadvantages associated with its adoption. This applies to all vessels, but more especially to very small craft. As just noted, a steel vessel with plates and angles 20 per cent. lighter than an iron one is equivalent to the latter in strength. (Plates and angles which would be, say, $\frac{8}{16}$ths thick in an iron vessel, become $\frac{8}{20}$ths in a steel ship.) But apart from strength, a certain objection is attached to reducing the thickness of plates. Thickness gives rigidity, and thus in some classes of very lightly constructed steel vessels, the effect of the water pressure upon the immersed surface is sufficient to cause the plating to buckle in between the transverse frames, so that the position of every frame is distinct on the outside surface. Severe pressure upon the bows in high-speed vessels makes this objectionable feature even more pronounced, and while it may be argued that this may not inflict any serious effects upon the strength, it certainly detracts from the appearance of the hull.

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* Should any of the samples tested show signs of failure by cracking or breaking in any way, and not fulfilling the test requirements, the whole of the material represented by such samples is rejected.

In some quarters, steel has been sadly abused for its rapid deterioration owing to corrosion. Probably, in some measure, there is truth in such a complaint against the metal. But it should be remembered that taking the same amount of corrosion in two plates of equal strength to, say, Lloyd's requirements, one of iron and the other of steel, the steel plate would only at first sight appear to be the worse of the two. But then the thinness of the steel plate is entirely against it in forming judgment. A $\frac{1}{16}$th off a plate $\frac{5}{16}$ths thick would appear more striking than $\frac{1}{16}$th off a plate $\frac{6}{16}$ths thick. It seems, therefore, that while some qualities of steel *may*, in some measure, show more signs of decay than wrought iron, it should also be remembered in judging the results that the steel was probably thinner to begin with.

Tests for Steel Castings.—The tests for steel castings in the hulls of ships are generally as follows:—Cast steel stern frames, rudders, steering quadrants, and tillers, must be subjected to percussive, hammering, and mechanical tests, in the presence of one of the society's surveyors, so as to ensure the material being of ductile quality. A tensile test is to be made on a piece taken from each casting, and the extension on a length of 8 in. is not to be less than 8 per cent., and the tensile strength not less than 28 tons, nor more than about 35 tons, per square inch. A cold bending test must also be made corresponding to each tensile test, and the sample must bend cold before fracture through an angle of at least 90°. Large stern frames cast in one piece must be allowed to fall on a hard flat ground (excavations being made to take the boss part and other projections) after being raised through an angle of 45°. Stern frames cast in more than one piece, and rudders, must be dropped from a height of from 7 to 10 ft., according to the design, shape, and weight of the casting. The casting in such case must subsequently be slung up, and well hammered with a sledge hammer, not less in weight than 7 lbs., to satisfy the surveyors that the castings are sound and without flaws, existing either originally, or developed as the result of the application of the preceding percussive tests.

Rivet Tests.—An equal tensile strength per square inch of section is required in rivets as in plates and angles. They should be of special quality, both soft and ductile, and capable of standing the following tests. One rivet per hundred should be subjected to a forge test.

1. *Temper Test.*—The rivet bar should be heated to a low cherry red, cooled in water of 82° Fahr., and then bent double round a curve the diameter of which is equal to the diameter of the bar.

2. *Forge Tests.*—To bend cold without fracture as shown in No. 2, fig. 5, x = diameter of the rivet.

3. To bend hot without fracture, as shown in No. 3, fig. 5, so that though the rivet has been nicked with a chisel at x, no signs of tearing are apparent.

4. The head to be flattened when hot as shown in No. 4, fig. 5, until the diameter is two and a half times the diameter at x.

Treatment of Plates and Bars in the Shipyard.—Even after the steel has been delivered in the shipyard, a hard brittle plate may often be detected in the operation of punching, the plate cracking round the rivet hole. The nature of the outer surfaces of the punchings also often expose bad material; a cracked creviced surface, together with a severely torn edge, point to the same defect. This is specially noticeable in bad iron plates.

In rolling a plate cold, the objectionable feature of cold-shortness (cold-brittleness) is sometimes discovered, and in the same operation with a heated plate, hot-shortness (hot-brittleness) may be detected.

The manipulation of a plate in the hands of the ships' platers may tend to cause deterioration in the quality of the material unless it be subjected to proper treatment. Thus, plates (such as counter plates and boss plates round the tail-end shaft) which have been severely hammered in order to shape them for their particular positions on the hull, and are, moreover, probably subjected to several heatings and coolings, should be annealed before being fixed in position in the vessel, in order to regain the uniformity in strength which any such severe processes as hammering and uneven cooling destroys.

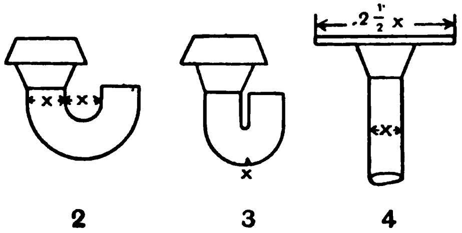

FIG. 5.—Rivet Tests.

Similarly, the severity of the operation of punching the holes for rivets in a steel or iron plate, so destroys the molecular arrangement of the material in the neighbourhood of the holes that, in order to regain the original uniformity of strength, the plates should either be annealed after punching, or else the holes should be rimed out. These features are fully recognized by the classification societies, and we find that important structural items in the material, such as stringer plates, sheer strakes, garboard strakes, and all buttstraps when about $\frac{10}{20}$ths of an inch in thickness and above, are to be carefully annealed, or else the holes are to be rimed after punching.

CHAPTER III.

CLASSIFICATION.

Purpose for which Classification Societies exist—Societies empowered to assign Load Lines—Government the supreme Authority for Assignment of Load Lines, and responsible for Seagoing Condition of Vessels leaving British Ports—Standard of Strength upon which Load Lines are assigned—Load Lines of Three Deck, Spar Deck, and Awning Deck Vessels—Grades of Class—Maintenance of Class—Unclassed Vessels.

Purpose for which Classification Societies exist.—A1 at Lloyd's is a phrase oftener used than fully understood, though every seaman knows that it conveys an idea of the good quality of, and seaworthiness of a ship.

Such an expression brings us into contact with a subject of paramount importance, viz., 'Classification,' and as a large proportion of seagoing vessels are 'classed,' and the structural strength in new vessels and the manner in which such structural strength has been maintained in old vessels determines the 'class' to which they belong, it will be well at the outset to obtain a clear idea of this matter of 'classification.'

A steel or iron ship is often compared, from the point of view of strength, to a beam or girder, and in many respects such a comparison may fairly be made. When iron or steel girders are used in the construction of bridges, buildings, etc., a very close approximation can be made to the nature and amount of the severest strains which may have to be borne. And thus the necessary strengths and dimensions of these girders can be arrived at almost entirely by calculation, provided that the quality of the material is thoroughly understood. But when we come to the actual ship girder, we find ourselves confronted by considerable difficulties and complications, which make the determination of the scantlings and disposition of the material in order to ensure sufficient strength, a matter which cannot be ascertained purely by calculation. The innumerable varying and sudden stresses which are experienced by ships in a seaway, when rolling and pitching in light, loaded, or ballast conditions, render accurate mathematical treatment impossible, although, as we shall show, by no means rendering mathematical approximation useless.

The other factor necessary in arriving at an adequate knowledge of required strength is experience. Thus we find throughout the history of iron and steel shipbuilding, continual changes have been made in the generally accepted rules, as experience has indicated their necessity.

All ships are built to carry. Some, as in the case of steam yachts, though two or three hundred feet in length, have little else to bear than the owner, his family, a few guests, the crew, bunker coals, stores, and provisions. Other vessels, such as tramp steamers, are built to carry cargo of great specific gravity. The former are so light that, in order to sufficiently immerse them, considerable quantities of permanent ballast are usually carried. In the latter, on the other hand, if the holds were entirely filled with cargo of the nature referred to, the vessels would be almost, if not entirely, immersed, and apart from considerations of strength —assuming them to be able to float—the question of stability, with little or no freeboard, would probably be a serious matter.

The purposes for which ships are built are innumerable, and to build all vessels which are similar in size and proportion, of equal structural strength, regardless of the work they have to do, would be absurd. What is more reasonable and sensible is to ensure that each vessel is sufficiently strong to satisfactorily perform her own work. To introduce as much structural strength into a cross-channel passenger steamer which has to carry little else than passengers, mails, and luggage, besides her own equipment, stores, and bunkers, as into a vessel of equal dimensions which has to carry, say, 1000 or 1500 tons of cargo to any part of the world, would be foolish in the extreme. Or even in the case of two purely cargo carrying vessels of identical dimensions, if one is intended to be solely employed in carrying a cargo of great density, such as coal, while the other is intended to carry a cargo of much less density, such as wool, the one amounting to say 3000 tons, and the other to only about 2000 tons, obviously it would be absurd to build each of these vessels to exactly the same scantlings, for either the one would be excessively strong, or the other dangerously weak. But, as stated, it is necessary that each vessel should be strong enough to do her own work.

The strength of ships, therefore, should be regulated by their proportions and maximum displacements, provided that enough freeboard remains to ensure sufficient stability and a condition of general seaworthiness.

It is clear that to study and tabulate the scantlings for every new ship lies outside the sphere of the shipowner. That shipbuilders, by their wide experience, would be vastly more capable of adequately dealing with the matter, is true, but then, without a fixed standard of strength, no two of them would either arrange their material alike, or arrive at the same strength in the finished vessel, even for similar vessels under similar conditions. Moreover, no such method of ship construction would be either satisfactory or acceptable to underwriters. From both owners' and underwriters' standpoint, standards of strength, both for maximum displacements and minimum freeboard, are absolutely essential.

Or in other words, a guarantee is required that the vessel is strong enough to carry with safety, and without injury to herself when experiencing the various and probable demands which may be made upon her strength, a certain load, which may not, under any conditions, be exceeded, and also that her design is such, that, with a minimum reserve buoyancy when properly loaded, she runs no risk of capsizing through deficient stability. With this aim in view, there exist several societies, which, by scientific and mathematical investigation coupled with long experience, have drawn up rules and tables of scantlings suited to all types of cargo and passenger vessels. The best known of these societies are Lloyd's Register, the British Corporation, and the Bureau Veritas. These societies save both shipowners and shipbuilders an immense amount of labour and trouble, at the same time providing general uniformity in strength, and a satisfactory guarantee of efficiency to the insurance societies for the vessels constructed under their rules. To carry out this system, the committees of these societies employ considerable numbers of surveyors, whose training and experience have specially fitted them for the work. The quality of the material used in the construction, the efficiency of the workmanship, the carrying out of their societies' rules and requirements, and the periodical survey for the renewal or alteration of the 'class' of the vessels placed in their hands, is their sole responsibility.

The Load Line Act of 1890.—Before the Load Line Act came into force in the year 1890, the overloading of ships, which was a source of danger from both a structural and stability aspect, was attended with loss of life at sea as well as loss of ships. The necessity for Government interference so impressed itself upon this country, that the passing of the Load Line Act was the final result, by which the Government became supremely responsible for the seagoing condition of all British vessels and vessels leaving British ports.

Societies empowered to assign Load Lines.—Hence, while the British Government has sanctioned Lloyd's Register, the British Corporation, and Bureau Veritas Classification Societies, to assign load lines to vessels classed by them, the Board of Trade still remains the supreme authority for such assignment. It is certainly true that these societies can build ships to whatever scantlings they please, but it is the work of the Board of Trade to ensure that a maximum load line be fixed strictly in accordance with the strength of such vessels with a reasonable percentage of reserve buoyancy.

Standard of Strength upon which Load Lines are assigned.—While considerable latitude is thus allowed in the disposal of material in the ship structure, the necessity for a *minimum* standard of strength is obvious. This is, moreover, essential in order that uniformity in the strength of the different types of vessels built be secured, while it does not necessarily follow that uniformity in the modes of construction will be a result. The standard of strength laid down for the guidance of all classification societies is that embodied by Lloyd's Rules for the year 1885. This gives the minimum structural strength for a minimum freeboard for all classes of vessels. Any society is at liberty to demand greater structural strength in vessels classed by them than that of the Board of Trade standard, and, naturally, they are individually responsible for efficient local strengthening.

Societies for the classification of vessels are thus at liberty to arrange and formulate their own methods of construction, and determine the scantlings of the material used in ships built to their particular classes. With uniformity of strength, uniformity in assigning the freeboard of every class of vessel is secured, since it must be in accordance with the Freeboard Act of 1890.

To the shipowner this subject of classification is of the greatest importance. If he wishes to add a new vessel to his fleet, and he is desirous of ensuring her being built to the highest class, he inserts a clause in his specification, or in the contract between himself and the builders, to the effect that she must be classed 100 A1 at Lloyd's, or to the corresponding highest class in any other society.

Load Line *of Three Deck, Spar Deck, and Awning Deck Vessels.*—There are four principal types of steel vessels considered in the Board of Trade Freeboard Tables, viz., Three Decked, Spar Decked, Awning Decked Vessels, and Sailing Ships. A vessel may belong to the highest class in any one of these types. The three decked type is the strongest vessel built, and is thus allowed the minimum freeboard with consequently the maximum immersion, displacement, and carrying power. Awning decked vessels are the lightest types of vessels built for over-sea voyages, and consequently are required to have the greatest freeboard, with smaller immersion, displacement, and carrying power. Supposing that into such an awning decked vessel, more structural strength than is required by Lloyd's Rules for 1885 is introduced, a comparison would be made between her increased strength and that required for a spar decked vessel, and a proportionate reduction made in the freeboard. Or, if a spar decked vessel were built in excess of the standard strength, a comparison would be made between her increased strength and that of a three decked vessel, and a proportionate reduction made in her freeboard also. But as the three decked vessel has already a minimum reserve buoyancy, additions of strength beyond that required by rule would obtain no concessions in the matter of diminished freeboard.

Grades of Class.—While it is customary for shipowners to have new vessels built to the highest class of their respective types, it does not follow that such vessels will always maintain the highest class; for example, at intervals of four years, Lloyd's require that vessels classed with them should be subject to special surveys. These special surveys are designated No. 1, No. 2, No. 3, and No. 4 respectively, and as long as a vessel maintains her structural strength, she maintains her class; but as soon as she begins to deteriorate, and suffer reduction in structural strength, her class may be reduced to 90A or 80A, which simply means that as she is now less able to carry the same deadweight as originally, her freeboard is increased until her carrying power is in accordance with her strength.

Maintenance of Class.—It is, however, possible, by carrying out certain repairs, to restore the vessel to her original strength and class. "If a vessel is at a port in the United Kingdom after the expiration of the prescribed period for survey, and is not subjected to the special survey then due before leaving the United Kingdom, the word 'Expired' is inserted against her character in the Register book; and in no case will a vessel be allowed to retain her class, if she has not been subjected to the whole of the requirements of the requisite special survey within twelve months from the date when the survey became due." (Lloyd's Rules.)

On the shipowner contracting with the shipbuilder for the building of his vessel to class, say, 100 A1 at Lloyd's, 3/3.1.1. Bureau Veritas, or B. S. of the British Corporation, the first work of the shipbuilder is to have drawn a set of plans upon which is shown the structural arrangement of the vessel in accordance with the instructions contained in the Classification Societies' Book of Rules, and the scantlings of each structural part, whether of iron, steel, or wood, are figured upon these plans. They are next sent to the classification society's registry through the local surveyors, where the scantlings are checked, and the special structural requirements of this particular vessel are considered. The plans are then returned to the shipbuilder with the necessary corrections or additions required clearly marked upon them. This is the first introduction the ship has to the classification society, but from that day to the time of her completion, she is the object of their constant attention. Indeed, throughout her existence, so long as she is 'classed' she is periodically subject to inspection by their surveyors. The steel must also be of the quality required by the particular society, and therefore such instructions accompany the specifications sent to the steel mills where the plates and bars are rolled, and the forgings or castings made. Before these are sent back to the shipbuilder, they must be tested by the classification society's testing surveyors, and the stamp of the society's approval must be upon them. As the work of building the ship proceeds, and the various parts are united, the ship surveyors are ever watching that the steel or iron has the test stamp upon it, that the plates and bars are to the dimensions indicated upon the corrected original plans submitted by the builder, that the connections of plates and angles, and the size and spacing of the rivets, are strictly in accordance with the rules of their society, and that the general workmanship is satisfactory. In this manner, the ship is daily under the eye of these surveyors.

Simultaneously with the building of the ship, the engines and boilers are constructed, and here again the work is under the superintendence of the society's engineer surveyors. Even the thicknesses of the plates and the minimum diameters for steel masts, size of wire for the rigging, weight of anchors and cables, are all determined in the Classification Societies' Rules, and the last mentioned are subjected to their tests. Appliances for life-saving, boats, belts, etc., are, however, all regulated by the Board of Trade.

When at last the vessel is completed, and the watertightness of ballast tanks, peak bulkheads, decks, etc., have been tested, and the whole work carried out to the satisfaction of the surveyors, the minimum freeboard for vessels of this class is permanently marked upon the ship's side. The shipowner is then provided with a Certificate of Registry, and the vessel is entered in the Register of the Society with which she is classed, and denominated according to her class and type. Thus, by having his vessel classed, not only has a shipowner the satisfaction of knowing that she is well built, but as she is periodically surveyed, he is further assured as to the maintenance of her strength, while in the event of his desiring to sell her, her class is a guarantee to the purchaser as to her structural condition.

Moreover, as the vessel will probably be insured when she proceeds to sea, her class is the only guarantee the underwriters have as to her strength and the condition in which she has been maintained.

Note.—Although it is customary for a shipowner who intends having a new ship classed, to have her built to the rules and under the supervision of the surveyors of the society with whom he purposes to have her classed, yet this is by no means an absolute necessity. A vessel may be built independently of all society rules, and still obtain a class. Before any society, however, would grant this, the vessel would require to be thoroughly surveyed by their surveyors, and after an accurate estimate had been made of her structural worth in comparison with their own particular standard, a class corresponding to one of the grades of the classification society in question would be assigned to her, with a maximum load line in accordance.

Unclassed Vessels.—That a ship should be classed with any society in order to receive a load line in accordance with her strength is not essential. Thus, many large shipowners, who employ thoroughly capable naval architects, design their own vessels, and determine the scantlings themselves. When such a vessel is completed and ready for sea and a load line is required, application is made to the Board of Trade (or to one of the societies empowered to assign load lines), who employ a large staff of ship, engineer, and nautical surveyors, by whom the vessel is thoroughly surveyed, and who fully report upon the workmanship and scantlings; and finally, a freeboard is assigned in accordance with the vessel's strength judged by the standard previously described. Such vessels are distinguished by the term 'unclassed,' though it should be clearly understood that an unclassed vessel is by no means necessarily inferior in any way to a classed one.

That Lloyd's present-day Rules may differ from their Rules of 1885, which is the standard of strength laid down by the Board of Trade for the guidance of all classification societies empowered to assign load lines, is true, yet it should be remembered that this difference is due to extended experience and fuller knowledge of the structural requirements of ships, and may be taken as a more perfect form of the older rules. It is also remarkable that this increased experience has rarely been followed by any reduction in scantlings, but rather by their augmentation. The result is, that Lloyd's own standard for classification is to-day higher than ever it was.

Notwithstanding the various criticisms which from time to time have been passed upon the rules for the construction of ships formulated by Lloyd's Registry, the fact remains that by far the vast majority of British vessels have been built to their requirements and classed with them, and, in addition to these, large numbers of foreign vessels are included also.

This, in itself, is sufficient to conclusively show how great is the confidence placed in Lloyd's by shipowners, and the general satisfaction which their rules have given.

With this fact in view, and remembering that in these days most new vessels are built to 'class,' it seems advisable to state, that in the treatment of ship construction in the succeeding sections of this book, the methods followed will be generally in accordance with the practice of Lloyd's Registry, though where any particular purpose may be served, we shall not hesitate to deviate from their rules, and describe other methods and practice.

CHAPTER IV.

OUTLINE OF PRINCIPAL FEATURES AND ALTERNATIVE MODES OF SHIP CONSTRUCTION.

Transverse and Longitudinal Framing—Form and Function of Parts—Butts in Transverse Framing—Framing in Double Bottoms—Regulations for Increasing the Number of Tiers of Beams—Compensation for Dispensing with Hold Beams—Necessity of thorough combination of Transverse and Longitudinal Framing—Structural Value of Shell Plating—Alternative Modes of Construction—Numerals for Scantlings.

Possibly the knowledge of ship construction possessed by many readers may be of a very limited character, and in this chapter it is simply proposed to briefly enumerate the principal parts in the structural arrangement of ships, so that the names of such parts may become familiar; and to give a general idea of their functions. This plan, it is believed, will simplify the course pursued in this work, and render the chapter on 'Stress and Strength' more intelligible, besides curtailing elaboration and explanation in the longest division of the book dealing exclusively with 'Construction.'

Framing.

Steel and iron ships are built on a combination of two systems of framing, viz., longitudinal and transverse.

Longitudinal Framing includes all girder forms of material which run in a fore and aft direction, whose function is to afford longitudinal strength.

Transverse Framing embraces all girder forms which cross the longitudinal framework at right angles, affording transverse or athwartship strength.

The strongest structure is obtained only when these two systems of framing have been intelligently woven together, the strength of the one co-operating with the strength of the other—that is, in relation to the work which, conjointly, they have to do. When this is accomplished, the whole is then covered by a skin, in the form of 'shell plating' and decks, which not only stiffens and strengthens the skeleton or framework, but adds enormously to the total strength of the ship considered as a compound girder.

Transverse Framing.—In order to preserve the transverse or athwartship form of a ship under all the conditions of stress to which ships are subject in carrying their various loads in smooth and wave water, a girder or frame is placed at intervals of from 20 to 30 or more inches apart, all fore and aft.

Fig. 6 gives an example of the simplest form of transverse framing. Here we have a half section of a comparatively small vessel showing such a transverse frame with what are known as ordinary floors. It consists of a frame bar, a reverse frame bar, a floor plate, a beam, and a pillar or stanchion. The efficiency of the complete frame depends upon the thoroughness of the combination of the various parts into one whole.

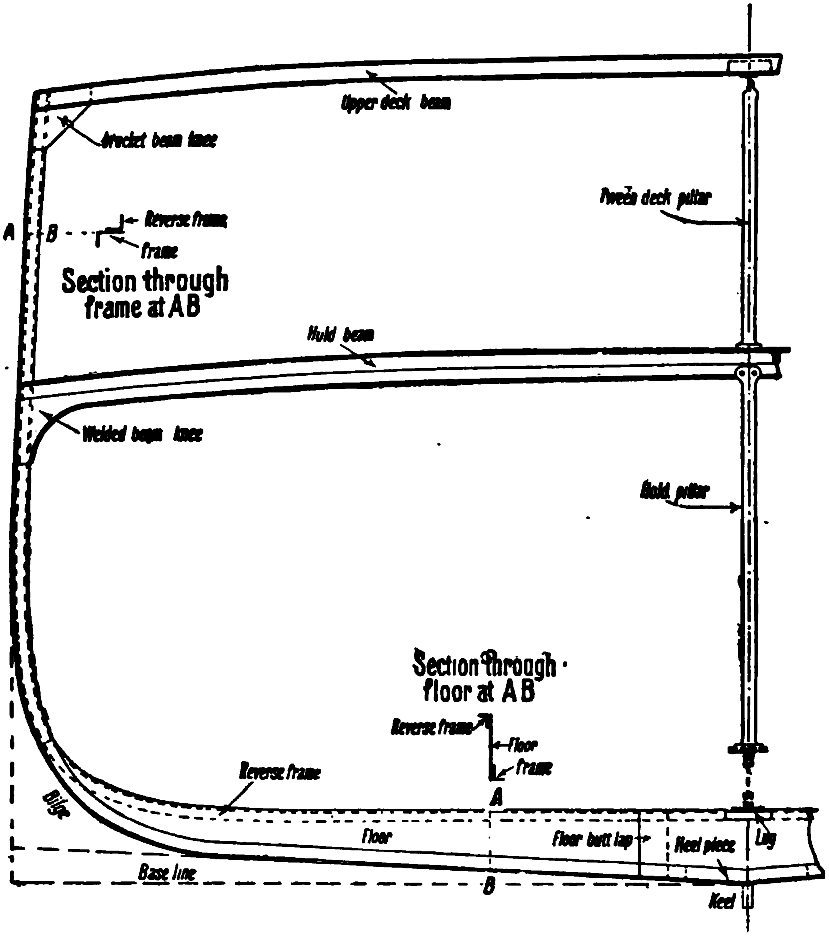
Upper deck beam
Bracket beam knee
'Tween deck pillar
A
B
Reverse frame
frame
Section through frame at AB
Hold beam
Welded beam knee
Hold pillar
Section through floor at AB
Reverse frame
floor
frame
Reverse frame
A
Bilge
Floor
Floor butt lap
Keel piece
Lug
Base line
B
Keel

FIG. 6.—Midship Section showing Transverse Framing with Ordinary Floors.

Frames.—The *frame bar*, in this system of framing, is continuous from the top of the keel to the gunwale, extending from the top of the keel to the bilge along the lower edge of the floor plate to which it is riveted.

Reverse Frames.—The *reverse bar* also extends continuously from the middle of the upper edge of the floor plate on the opposite side to the frame (shown by dotted lines on the section) up the bilge, then on to the frame bar to the gunwale except in the smallest vessels, though the alternate reverse bars do not usually extend to this height.

Floor Plates.—The *floor plate* extends from bilge to bilge, either in one plate, or in two plates butted (joined end to end) alternately on either side of the centre line. The frame and reverse bars are riveted to its lower and upper edges respectively, converting the plate into a girder with top and bottom flanges, which strengthen it to resist athwartship buckling. (See fig. 6.)

The height of the bilge ends of the floor plate above the base line is usually about twice the depth of the floor at the middle line of the ship; and at three-quarters the half-breadth out from the middle line it should be at least half the depth of the floor plate at the middle line.

The advantage of carrying the floor plate round the turn of the bilge must be obvious, strengthening what is liable to be a weak place in the framing, especially in very square-bilged ships. At such a corner, 'working' is more liable when the vessel is subject to the severe stresses which are experienced among waves, tending to produce alteration in the transverse form.

Beams.—The beam is a steel or iron bar, uniting (in a single-decked ship) the uppermost extremities of the frame, and preventing, by its own tensile strength and rigidity, the tendency of the frame heads to open wider apart from each other, or to approach each other when the vessel is subject to stresses consequent upon loading, or from the pressure of the water upon the immersed skin of the ship. Beams thus perform the function of both struts and ties.

Here, again, much depends upon the efficiency of the means of connection, and also in thoroughly supporting the angular connection of the beam to the frame. Hence it is necessary to form a web of plating (beam-knee) which should extend at least two and a half or three times the depth of the beam down the frame to which it is securely riveted. We shall refer more fully to this in Chapter VII. Owing to the depth of the vessel illustrated in fig. 6, additional transverse support is required to the sides between the weather deck and the floors. An additional tier of widely spaced beams is thus introduced.

Pillars.—It is scarcely necessary to say that the shorter a bar is, the more rigidity does it possess, and also, that the fullest efficiency of any structure whose strength is made up of a number of parts, can only be fully developed when such parts are combined in the most perfect manner so as to cause the entire combination to act as one. Hence, in order to develop the full efficiency of the transverse frame, its several parts must be 'tied,' in order to prevent their acting independently of one another. Pillars are therefore introduced, uniting the beam at the centre with the floor at the centre. These act both as struts and ties, preserving the distance relationship of these opposite parts of the structure. Moreover, without pillars, any crushing strain upon the sides of a ship might tend to cause the beam to spring up at the centre (see fig. 22), its great length reducing its rigidity and resistance to any such strain; on the other hand, they are needed to support the numerous and varying loads,—both stationary, as winches, windlasses, etc., and temporary, as deck cargoes. Where the beam is very great, additional pillars, termed quarter pillars, are introduced between the centre ones and the sides of the ship, or else a substitute of some kind is required.

Butts of Frame and Reverse Frame.—Though both the frame and the reverse frame have a break in their lengths at the centre line above the keel, in each case it is intended that the strength of these bars be continuous. To unite these ends by such means as will ensure this is therefore necessary. In the case of the frame,' this is done by fitting a *heel piece* (a piece of angle iron about 3 ft. long, of the same size as the frames), on the opposite side of the floor and covering the butt, and in the case of the reverse bar, by fitting a short covering piece on the opposite side of the floor also. (See figs. 6 and 9.) These butt-covering bars also perform other services in the ship structure, as will be shown later.

Transverse Framing in Double Bottoms.—The system of so constructing the bottoms of vessels as to make them capable of carrying water for trimming purposes or as ballast has become more and more universal during recent years.

The earlier forms of these double bottoms were called M'Intyre tanks, after the name of the inventor. At first these tanks were so built that the transverse framing was maintained in the usual way, the inner bottom being formed by laying the plating upon fore and aft girders standing on top of the ordinary floors. In some cases the inner bottom plating extended horizontally out to the ship's side, where it was made watertight by fitting angle collars round the frames. In the most common form of M'Intyre tank, however, the tank side in each wing is formed by turning the inner bottom plating down perpendicularly to the bilge. Here, again, the frame bar was sometimes continuous through the tank side, or, as it is more usually called, the tank margin plate. But generally, the frame bar, especially in vessels now fitted with these tanks, is cut at the tank margin plate, and a continuous angle bar fitted, making the connection between the tank side and the outer shell plating watertight.

The continuity of the transverse frame strength in such cases is maintained by connecting the frame legs to the tank side by large bracket plates. Though M'Intyre tanks are less adopted than formerly, they are still fitted in some cases. Such a tank is illustrated in a midship section, fig. 71.

The double bottom water-ballast tank now most commonly adopted is that known as the 'cellular double bottom.' The transverse framing of this system (and longitudinal framing dotted) is illustrated in fig. 7.

Examination of the diagram shows the arrangement of the transverse framing to be somewhat interfered with, though, in effect, this modified arrangement is identical in principle with that previously described for vessels with ordinary floors.

The water ballast tank extends from margin plate to margin plate, and from the keel to the top of the floors. Here we usually find that a continuous deep plate runs fore and aft through the centre of the tank (centre keelson or centre through-plate).

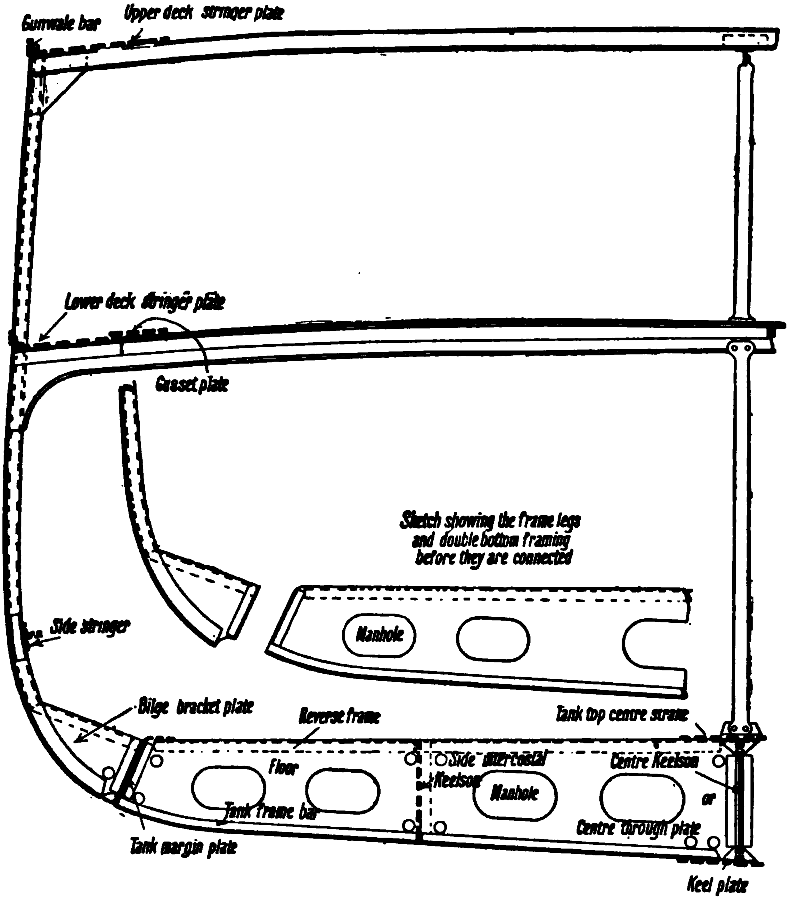
Gunwale bar
Upper deck stringer plate
Lower deck stringer plate
Gusset plate
Sketch showing the frame legs and double bottom framing before they are connected
Manhole
Side stringer
Bilge bracket plate
Reverse frame
Tank top centre strake
Floor
Side intercostal keelson
Manhole
Centre Keelson or Centre through plate
Tank frame bar
Tank margin plate
Keel plate

FIG. 7.—Midship Section showing Transverse Framing in a Vessel with a Cellular Double Bottom, also the Longitudinal Framing (dotted).

The continuity of the floor plate is necessarily interrupted, but the continuity of the transverse strength is maintained by connecting the floors to the centre through-plate by means of angles. The floors at the middle line are much deeper than required for ordinary floors, thus permitting a good connection, and somewhat compensating for the break in the continuity of the frames and reverses. The outer ends or extremities of the floors, called bracket plates, extend to exactly the same height as in similar ships with ordinary floors. But again, at the bilge, we observe that in order to form the outer boundary of the cellular bottom tank, the floors have to suffer interruption in continuity in order to allow the margin plate to pass continuously fore and aft, and fit hard on to the shell plating. However, by means of angle connections, and a considerable depth of floor at this place, a minimum for which is definitely stated in Lloyd's Rules (margin plate width), a good connection is made to the bracket plate, or tank knee as it is sometimes called, and the shape of the floor is preserved to the height prescribed.

In order to ensure the watertightness of the tank at this place, a continuous bar is fitted to the lower extremity of the margin plate, to connect it to the outer bottom. This necessitates another break in the continuity of the frame bar. The depth of the floor plate, however, enables a satisfactory connection to be made between the transverse framing inside and outside of the tank, by means of the bracket plate already mentioned. In exceptional cases the frames have been preserved continuously from keel to gunwale, and the watertightness at the margin plate effected by fitting angle collars round the frames for the whole length of the tank. The reverse bar is also intercostal between the centre keelson and the margin plate, and then again commencing outside the margin plate, is continued along the upper edge of the bracket plate, and up the frame bar to its prescribed height.

In all other respects, the upper framing, beams, pillars, and their connections, are identical with those in the ordinary system previously referred to in fig. 6.

Regulations for increasing the number of tiers of Beams.—So far, we have only dealt with a small type of vessel requiring but two tiers of beams. As vessels increase in size, however, not only for convenience and adaptation for carrying cargo, but for reasons of structural strength, more tiers of beams, which may or may not be sheathed with a wood or steel deck, are introduced. If the vessel is classed, these are regulated by the rules of the classification society. Thus, we find that vessels classed at Lloyd's, when over 15 ft. 6 in. from top of keel to top of upper deck beam at centre, require in addition to the weather deck, an extra tier of beams in the hold, which may be widely spaced—on every tenth frame—(see fig. 6); and when 24 ft. is exceeded, still another tier of beams is required.

Compensation for dispensing with Hold Beams.—The introduction of an extra tier of beams in a ship of, say, 16 ft. in depth, may, however, prove a source of inconvenience to a shipowner in the stowage of certain kinds of cargo, and a similar inconvenience may also arise in the introduction of the third tier of beams in a vessel of, say, 25 ft. depth.

In such cases, by modifying the transverse framing, these lowermost tiers of beams could be dispensed with, in the manner illustrated later in this chapter. First of all, we observe that these additional tiers of beams are required for purposes of strength. With ships of greater depth, and naturally we infer, of greater breadth, the increased immersion produces vastly increased stress from the external pressure of the water, tending to crush in the sides of the vessel.

Moreover, the loading of heavy cargo tends to distort the transverse form. Thus additional tiers of beams, supported from keel to uppermost deck by pillars, become necessary, unless a satisfactory method of compensation can be provided. This can be done by increasing the strength and rigidity of the transverse framing, the details of which method are fully described a little later.

Longitudinal Framing.—We have already observed that the special function of transverse framing is to preserve the transverse form, when experiencing the numerous and ever-varying stresses to which ships are subject. In a like manner, and to a much greater extent, especially in vessels of great length, there is the tendency to alter in longitudinal form; as in their pitching movements they are subject to immense differences and sudden changes in the buoyant support afforded by the water, and to sudden twisting stresses when crossing skew seas. Moreover, such stresses may be greatly increased, especially under certain conditions, by the filling of large peak or other ballast tanks at the ends of a vessel, or in stowing very heavy cargo towards the extremities.

Of what paramount importance does an efficient arrangement of longitudinal framing become, will therefore be obvious. Thus, we find that along the bottom, on the bilge, and up the sides of a vessel, are a number of girders of various forms extending all fore and aft, the continuity of whose strength is most rigidly maintained.

Keelsons and Stringers.—Fig. 8 shows the same section as fig. 6 with the longitudinal framing introduced. We may notice that all longitudinal girders of whatever form, on the bottom of the vessel between bilge and bilge, are termed *keelsons*, and those on the sides above the bilge, *stringers*. The name given depends, not so much upon the form of the girder section, as upon the locality in which it is placed. The most important keelson girder is that standing upon the top of the floors at the middle line. It is composed of a vertical plate with two large angles on the top, and two on the bottom, the whole being mounted by a thick plate called a *rider plate*. This girder is termed the *centre keelson*, and really forms the backbone of the ship.

In order to prevent the floor plates tripping, that is, inclining either forward or aft, and to afford strength and stiffness to the shell, it is usual to introduce what is termed an intercostal girder or *side keelson*, so named because it is composed of plates fitted intercostally between the floors in a continuous line all fore and aft, and connected to them by angles. In very small vessels, somewhat similar plates are fitted, whose height terminates at the upper edge of the floors. These are named *wash plates*, their function being to prevent any water which may have drained into the bilges, dashing from side to side when the vessel rolls. This is also one of the functions of side intercostal keelsons. But in larger vessels, the plates are carried above the floors between two angles as shown in fig. 8, and thereby converted into a continuous keelson. Keelsons may be built up in a variety of ways according to the dimensions and proportions of the vessel. These are more fully dealt with in Chapter VII.

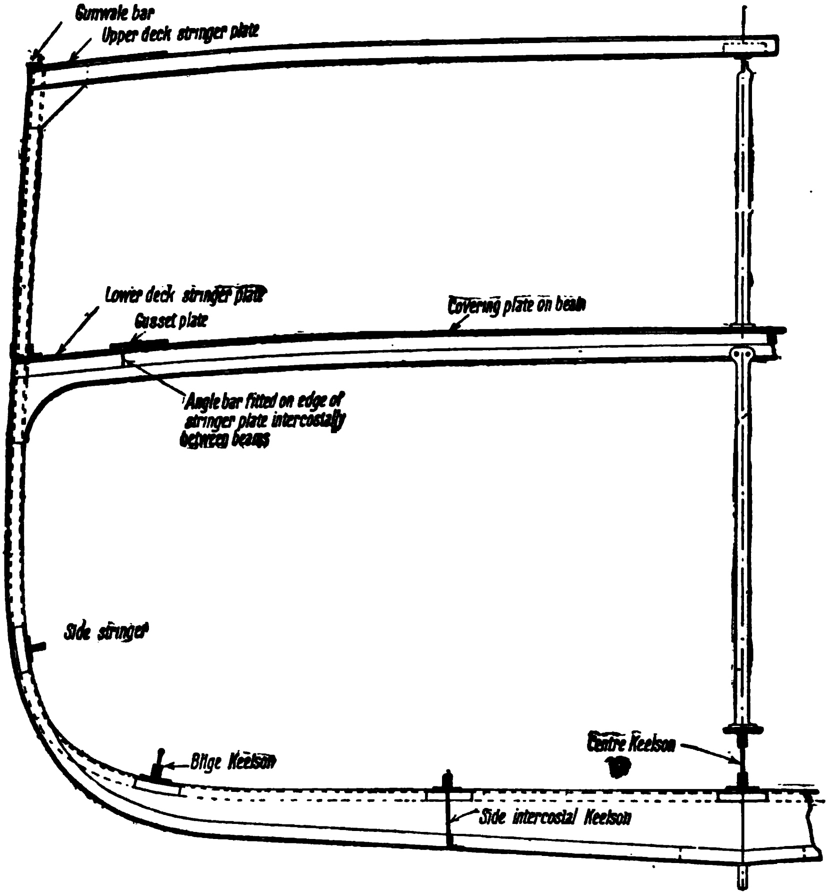
Gunwale bar
Upper deck stringer plate
Lower deck stringer plate
Gusset plate
Covering plate on beam
Angle bar fitted on edge of stringer plate intercostally between beams
Side stringer
Bilge Keelson
Centre Keelson
Side intercostal Keelson

FIG. 8.—Midship Section showing the Longitudinal and Transverse Framing combined, in a Vessel with ordinary Floors.

The next girder is on the bilge, and is called a *bilge keelson.*

Further up the vessel's side is a small girder, known as a *side stringer* (or it may be an upper bilge stringer).

Deck Stringers.—At the gunwale, and on the lower tier of beams, are broad continuous plates fitted on the ends of the beams. These are *deck stringer plates,* and form most valuable girders in conjunction with the beams. Wherever a tier of beams is fitted, whether a wood or steel deck is, or is not laid, this thick stringer plate is always to be found.

Centre Through-Plate.—In fig. 7 the longitudinal girders are shown (dotted lines) in conjunction with the transverse framing of the double bottom. Extending continuously down the middle line, and standing on the plate keel, is a deep plate, of the depth of the floors and tank. Indeed, the depth of the floor is regulated by the depth of this plate, the minimum width of which is fixed by the classification society. Two large angles on the top and bottom, mounted by a thick plate forming part of the tank top, make up the combination forming the *centre keelson.* It is also known as the *centre through-plate,* or *centre girder.*

Intercostal Keelsons.—The next girder is usually intercostal, the floors being continuous, as a general rule, in merchant vessels. This is known as a *side* or *intercostal keelson.* Its continuity is maintained by connection to the floors by means of angles.

Margin Plate.—At the bilge is the tank side, or margin plate, extending continuously fore and aft. This naturally forms an efficient bilge keelson, though not known by that name. Above the bilge, the arrangement of stringers is similar to that for the ship with ordinary floors.

Necessity of thorough combination of Transverse and Longitudinal Framing.—Even viewed separately, although both the transverse and longitudinal framing are absolutely essential for the work to be done, yet neither could possibly perform its own duty without the aid of the other. Whenever a longitudinal girder crosses a transverse frame, it ought to be carefully and thoroughly connected with it, if necessary, by the aid of small pieces of angle iron, or lugs, as they are often termed. For instance, in fig. 8 we find that the centre keelson is riveted to every reverse frame that it crosses on the top of the floors by means of its own bottom bars. But in order to get a doubly secure connection, a short piece of reverse bar (lug piece) is riveted to the other side of the floor, through the horizontal flanges of which the bottom bars of the keelson are riveted also. This same lug forms the covering piece for the reverse frame butt. The same principle of connection is applied to all the other keelsons and stringers wherever practicable.

Structural Value of Shell Plating.—When the skin, or shell plating, is worked over this framework, the effect is an enormous contribution to both transverse and longitudinal strength by more effectually binding together the whole structure into a single compound girder. Such a mode of construction, where one part is interdependent upon another for the utmost development of its own strength and rigidity, must commend itself.

Fig. 10 shows the vessel whose framing has been illustrated in figs. 6 and 8 with the shell plating in addition, and similarly fig. 11 shows the vessel whose framing has been illustrated in fig. 7, with the modification in the framing caused by the hold beams being dispensed with and web frames and stringers introduced as compensation.

The transverse framing stiffens and assists the longitudinal, and the longitudinal stiffens and assists the transverse, in doing each its own work. The whole system of the structural work of a ship is based upon the principle that unity is strength. Each of the innumerable parts performs its work in conjunction with the adjacent parts to which it is closely related, thereby contributing to the perfection of the efficiency of the ship girder. Thus many severe stresses, which would at first appear to be of a local character, become general, simply because the particular part upon which, perhaps, they are first experienced, communicates a share of the stresses through the other girders which cross and are attached to it, to the area around. In this manner the stress is distributed over the structure, its local severity reduced, and the possibility of evil results minimized.

Fig. 9 is a midship section of a large vessel, showing the longitudinal and transverse framing and the shell and deck plating. It also furnishes the name of each structural part, which no doubt may be of assistance to many readers in traversing the following pages.

ALTERNATIVE MODES OF CONSTRUCTION.

Assuming, in the case of a vessel to be classed 100 A1 at Lloyd's, that all the preliminary work of fixing the dimensions, and getting out and approving of the design and general arrangement has been satisfactorily concluded, before any steps can be taken in the work of construction, structural plans must be prepared by the shipbuilder, and submitted for the approval of Lloyd's Committee. These plans usually consist of a midship section, which gives a transverse view of the structure of the vessel amidships; a profile, showing a longitudinal sectional elevation (see figs. 48 and 49); and sometimes a deck plan; and upon these plans, the sizes or scantlings of all iron, steel, or wood, forming structural parts of the vessel, are distinctly marked according to the requirements of Lloyd's Rules.

As we have previously observed, in the case of a classed vessel the responsibility of structural strength, in relation to the weight to be carried (or the freeboard), is borne by the classification society; hence both builders and owners are relieved from this, so long as the workmanship is of a thoroughly satisfactory nature. However, as the classification societies provide alternative modes of arriving at the required structural strength, the owner has the option, under the guidance and advice of his naval architect, of making the choice of the system most suited to his requirements.

A ship is a girder composed of a host of smaller girders which comprise the framework. In the nature or the design of the framing the shipowner

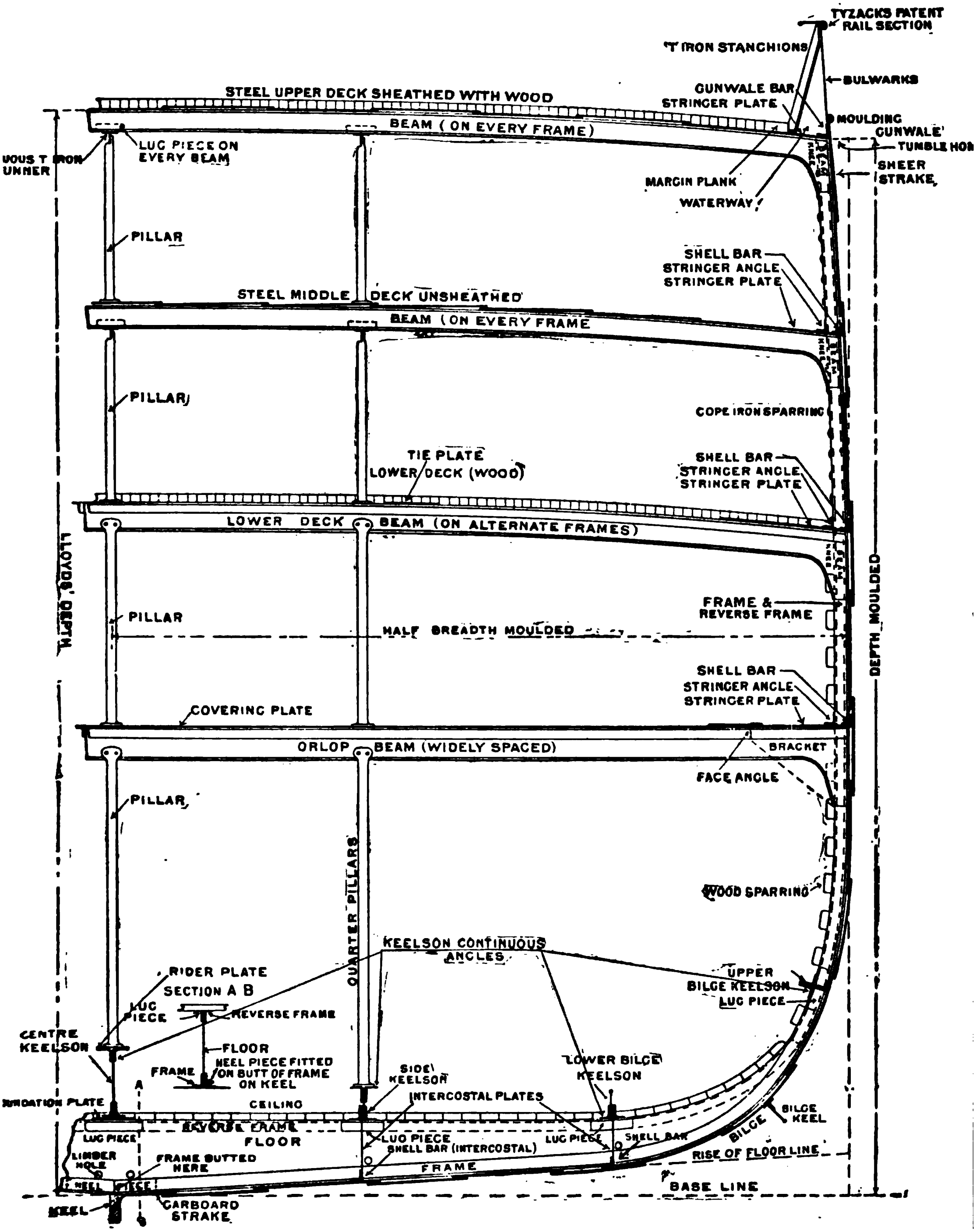
TYZACKS PATENT RAIL SECTION
T IRON STANCHIONS
BULWARKS
GUNWALE BAR
STRINGER PLATE
MOULDING
GUNWALE
TUMBLE HOM
SHEER STRAKE
STEEL UPPER DECK SHEATHED WITH WOOD
BEAM (ON EVERY FRAME)
UOUS T IRON UNNER
LUG PIECE ON EVERY BEAM
MARGIN PLANK
WATERWAY
PILLAR
SHELL BAR
STRINGER ANGLE
STRINGER PLATE
STEEL MIDDLE DECK UNSHEATHED
BEAM (ON EVERY FRAME
PILLAR
COPE IRON SPARRING
TIE PLATE
LOWER DECK (WOOD)
SHELL BAR
STRINGER ANGLE
STRINGER PLATE
LOWER DECK BEAM (ON ALTERNATE FRAMES)
LLOYDS' DEPTH
FRAME & REVERSE FRAME
PILLAR
HALF BREADTH MOULDED
DEPTH MOULDED
SHELL BAR
STRINGER ANGLE
STRINGER PLATE
COVERING PLATE
ORLOP BEAM (WIDELY SPACED)
BRACKET
FACE ANGLE
PILLAR
QUARTER PILLARS
WOOD SPARRING
KEELSON CONTINUOUS ANGLES
UPPER BILGE KEELSON
LUG PIECE
RIDER PLATE
SECTION A B
LUG PIECE
REVERSE FRAME
CENTRE KEELSON
FLOOR
KEEL PIECE FITTED ON BUTT OF FRAME ON KEEL
FRAME
A
SIDE KEELSON
LOWER BILGE KEELSON
INTERCOSTAL PLATES
UNDATION PLATE
CEILING
REVERSE FRAME
FLOOR
LUG PIECE
LUG PIECE
SHELL BAR (INTERCOSTAL)
LUG PIECE
SHELL BAR
BILGE KEEL
BILGE
RISE OF FLOOR LINE
LIMBER HOLE
FRAME BUTTED HERE
FRAME
KEEL PIECE
BASE LINE
KEEL
GARBOARD STRAKE

FIG. 9.—Midship Section of Merchant Steamer.

is free, to some extent, to exercise his choice. This can probably be best illustrated by the aid of the diagrams figs. 10, 11, and 12.

With Hold Beams.—Fig. 10 is a midship section of the vessel whose transverse framing we have already examined in fig. 6. She has a bar keel, and is built on the ordinary floor system. Being over 15 ft. 16 in. in depth from the top of the keel to the top of the upper deck beams at centre with the normal amount of camber, this vessel requires two tiers of beams. But while the beams in the upper tier are placed on every frame (2 ft. apart), the beams in the lower tier, which are exceptionally strong, are only

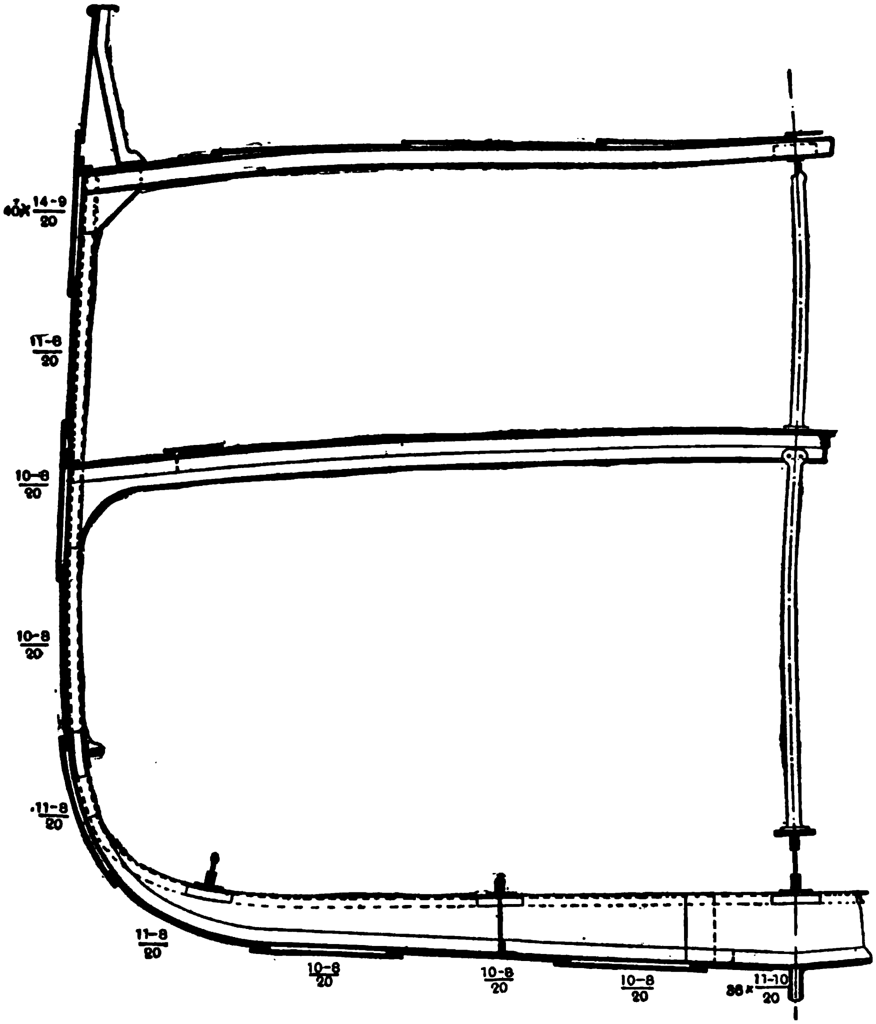

Fig. 10.—Midship Section of Vessel requiring two Tiers of Beams with ordinary Frames and Floors.

required on every tenth frame (20 ft. apart). The transverse framing, supporting the side shell plating, is made up of two angle bars (the frame and reverse frame) fitted back to back, and the longitudinal frame girders are as shown in the section.

Web Frames in lieu of Hold Beams.—Fig. 11 is a midship section of the same vessel as shown in fig. 7, and is of exactly the same dimensions and external form as fig. 10. In this case, the vessel has a side bar keel, and is fitted with a double bottom. The hold beams are dispensed with, and in lieu of them, transverse web frames are spaced on every sixth

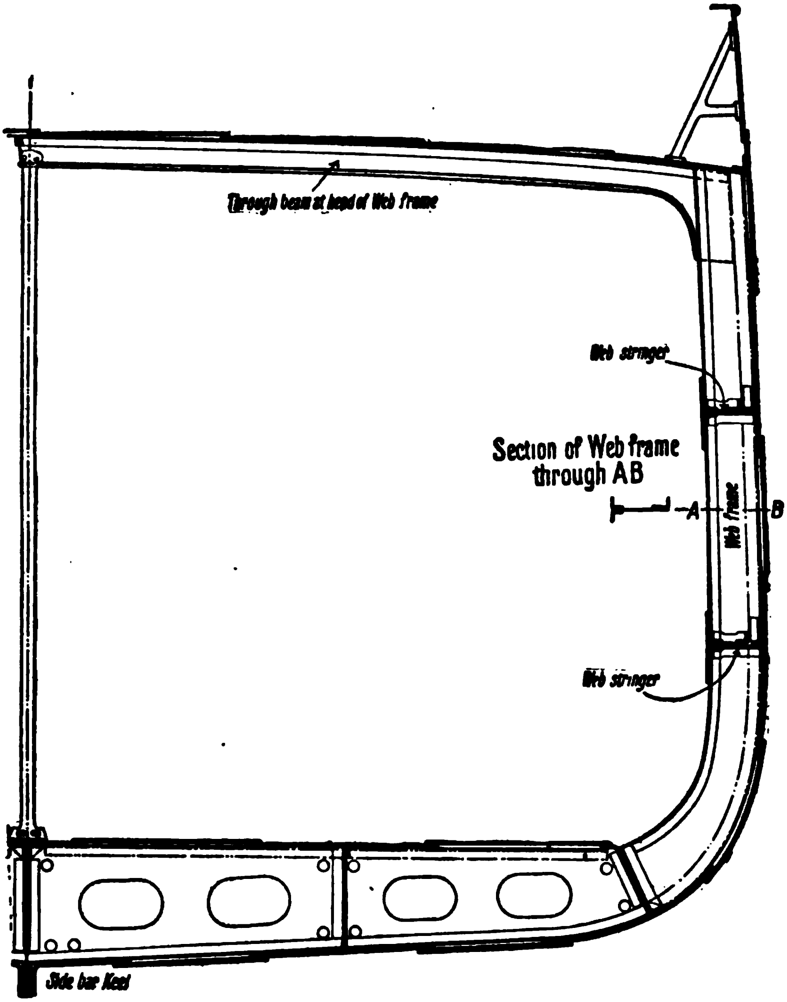
Through beam at head of Web frame
Web stringer
Section of Web frame through AB
A
B
Web frame
Web stringer
Side bar Keel

Fig. 11.—Midship Section showing Hold Beams dispensed with, and Compensation in the form of Web Frames and Stringers introduced.

frame throughout the vessel's length. A section at a web frame is shown. It consists of a web of plating 15 in. wide, extending from the tank side to the upper deck beams. It is attached to the shell plating by

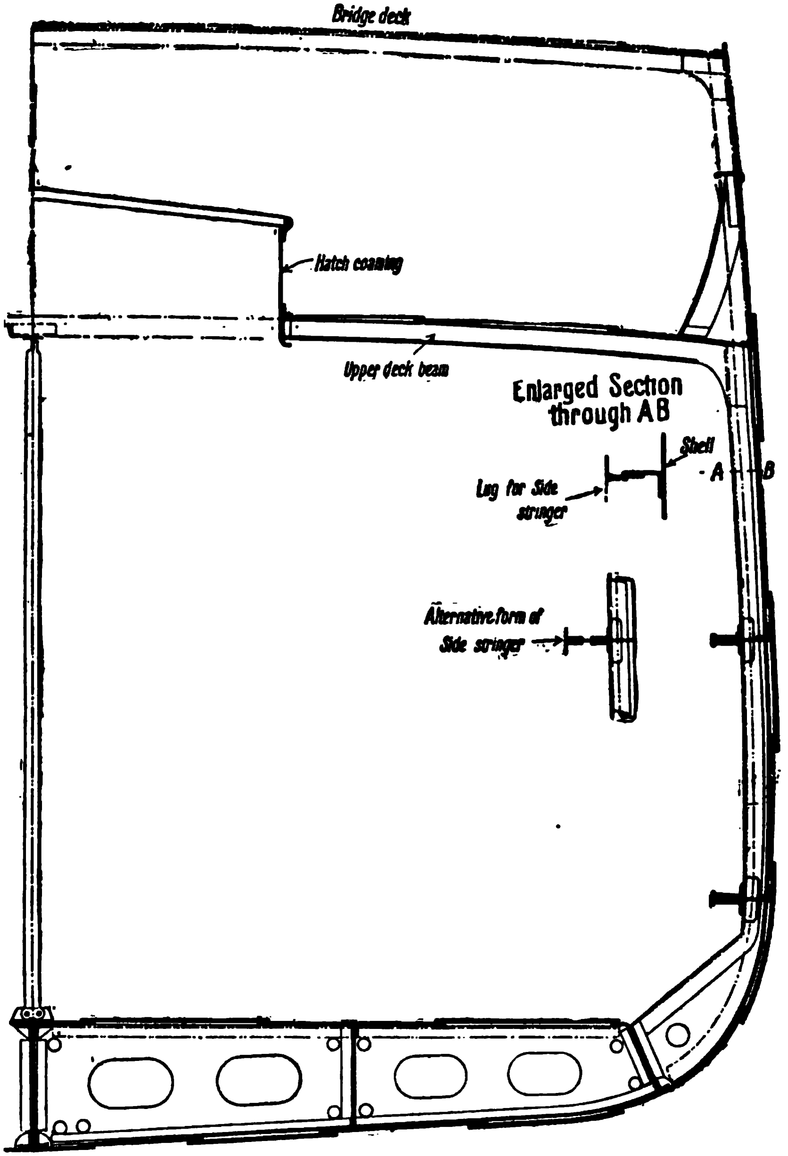
Bridge deck
Hatch coaming
Upper deck beam
Enlarged Section through AB
Shell
A
B
Lug for Side stringer
Alternative form of Side stringer

Fig. 12.—Midship Section showing Hold Beams dispensed with, and Compensation in the form of Deep Framing introduced.

an angle of ordinary frame size, and has two smaller angles fitted on its inner edge, or a single bar of larger size (equivalent sectional area) may be substituted. (When there is no double bottom, the web frame blends into the ordinary floor, and forms a complete continuous girder from gunwale to gunwale, and the transverse frames between the web frames are similar to those shown in fig. 10.) The longitudinal framing consists of two web stringers fitted intercostally between the web frames. When the beams at the head of the web frames are continuous from side to side, they are fitted of extra strength, but elsewhere they are similar to the upper deck beams shown in fig. 10.

Deep Framing in lieu of Hold Beams.—In fig. 12 the hold beams are again dispensed with, and compensated for by adopting what is known as deep framing. These deep frames, unlike the web frames, are upon every frame, and are made up of two large angles fitted together as shown on the midship section, fig. 12, which, in combination with the side stringers, possess strength and rigidity fully compensating for the omission of the hold beams.

Several alternative forms of side stringers may be adopted, one of which is shown in the diagram fig. 12. It may also be pointed out that when the deep frame system is adopted, the tank bracket knees should be of extra depth so as to provide ample support to the bilge, and the beam knees to the lower tier of beams should be three times the depth of the beam.

The adoption of any one of the foregoing systems of framing would in no way interfere with a vessel's obtaining the highest class with any classification society. On coming to vessels of larger dimensions than the one with which we have been dealing, it is natural to expect that the depth and thickness of the transverse framing should increase, and that a greater number of side stringers should be required. But as soon as the depth exceeds 24 ft., we have seen that an extra tier of beams is required, and the vessel, assuming that full scantlings have been adopted, becomes of three deck type.

However, that the vessel will have three tiers of beams does not necessarily follow; for, just as in a two deck vessel the lower tier of beams may be dispensed with, in like manner, the lowest tier in a three deck vessel may be dispensed with by fitting in lieu, either web frames up to the middle deck, or deep framing.

Fig. 48 shows the transverse framing of a three deck vessel of 34 ft. depth from keel to upper deck (not shelter deck) beam at centre (having the normal camber), with deep framing in place of the omitted hold beams.

Numerals for Scantlings.—In order to ascertain the scantlings of the material shown on the plans submitted to Lloyd's Committee, their rules give the following instructions:—

Assuming that the vessel is to be of full strength with, therefore, maximum rule scantlings,—add together (measurements being taken in feet) the girth of the half midship frame section of the vessel, measured from the centre line at the top of the keel to the upper deck stringer plate; half the moulded breadth; and the depth (Lloyd's). The sum of these numbers gives what is known as the *1st numeral.* By multiplying the 1st numeral by Lloyd's length, the *2nd numeral* is obtained. By means of the 1st numeral, the sizes and thicknesses of all frames, reverse frames, depth and thickness of ordinary floors, thickness of bulkheads, and diameter of pillars are found from the tables in Lloyd's Book of Rules.

The greatest breadth of the vessel at each deck regulates the size of the beams for each respective deck.

The depth of the vessel regulates the number of tiers of beams, and the number of stringers. The 2nd numeral, both alone and in conjunction with the proportion of length to depth, regulates all the remaining scantlings, and the number of complete or partial steel or iron decks. It should be noted, however, that for vessels of over 24 ft. in depth (Lloyd's)—'three deck'—notwithstanding the fact that the lowest tier of beams may be dispensed with by making compensation in some form or other, the *1st numeral* is obtained *by deducting* 7 from the sum of the half girth, half moulded breadth and depth; and the *2nd numeral* by multiplying the 1st numeral thus obtained by the length in the usual way. For the lighter types of vessels, known as 'spar' and 'awning' deck, the 1st numeral is obtained by adding together the half girth and Lloyd's depth taken to the *main* deck (see fig. 14) together with the half moulded breadth, and the 2nd numeral is the product of the 1st numeral by the length of the vessel. (See fig. 9 for Lloyd's depth.)

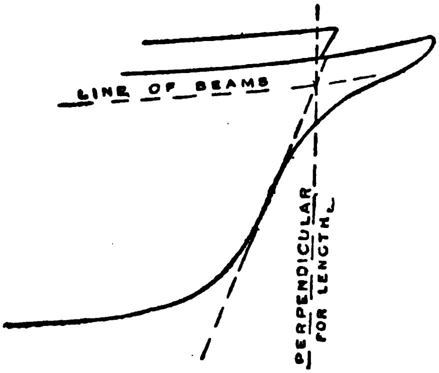

FIG. 13.—Length between Perpendiculars.

In the book of Lloyd's Rules, these numerals are all arranged in a graduated tabular form, and adjoining them is given the scantling of the material, or structural item or items which they govern. By referring to these rules, and the notes accompanying them, the particulars of scantlings given along with the midship section (fig. 10) are found, as are also the tables of scantlings on pages 111 and 112.

After considering the special features of the vessel in question, and adjusting the scantlings where necessary, the plans are returned to the shipbuilder, who sees to the ordering of the steel and iron, and whose draughtsmen proceed with the work of drawing the detail structural plans for the workmen in the shipyard.

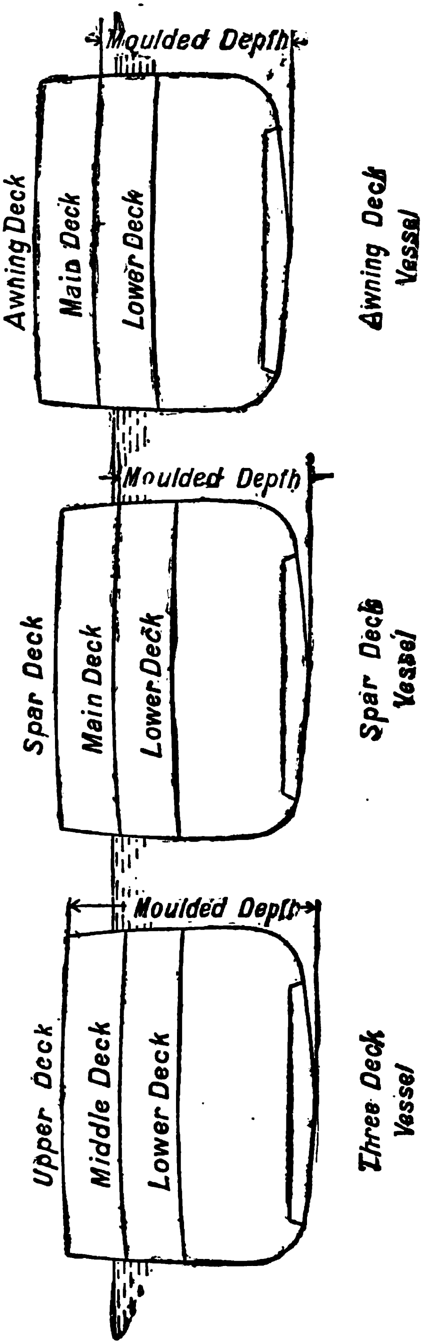
Moulded Depth
Awning Deck
Main Deck
Lower Deck
Awning Deck Vessel
Moulded Depth
Spar Deck
Main Deck
Lower Deck
Spar Deck Vessel
Moulded Depth
Upper Deck
Middle Deck
Lower Deck
Three Deck Vessel

Fig. 14.

Definitions of Important Terms.

1. **Length between Perpendiculars.**—This is the length usually agreed upon by shipowner and shipbuilder when contracting for a new vessel, and is that generally understood when speaking of the length of a vessel. For vessels with straight vertical stems, it is taken from the foreside of the stem bar to the aft side of the stern post. When the stem is raked, that is, inclined forward from the foot, the length is measured from the fore side of the stem bar at the upper deck. Should the vessel have a clipper or curved stem, the length is measured from the place where the line of the upper deck beams would intersect the fore edge of the stem if it were produced in the same direction as the part below the cutwater. (See fig. 13.)

2. **Length over all** is the length measured from the foremost tip of the stem bar to the aftermost tip of the overhang of the stern. For vessels with straight stems it is practically the extreme length.

3. **Lloyd's length** is the same as the length between perpendiculars, except that the length is taken from the after side of the stem to the fore side of the stern post.

4. **Registered length** is measured from the fore side of the tip of the stem bar to the after side of the stern post.

5. **Extreme breadth** is measured over the outside plating at the greatest breadth of the vessel. This is also the **Registered breadth.**

6. **Breadth moulded** is taken over the *frame* at the greatest breadth of the vessel.

7. **Depth moulded** is measured in one, two, and three deck vessels at the middle of the length, from the top of the keel to the top of the upper deck beams at the side of the vessel. In spar and awning decked vessels, the depth moulded is measured from the top of the keel to the top of the main deck beams at the side of the vessel (see fig. 14).

8. **Lloyd's Depth.**—This is somewhat different. It is required that all upper decks, and all main decks in spar and awning decked vessels (see fig. 14) have a round upon them, the height of which at amidships amounts to a quarter of an inch for every foot of the greatest breadth of the deck. This is termed 'camber,' 'round up,' or 'round of beam.' This is added to the moulded depth, and gives Lloyd's depth. With this modification, it is otherwise the same as No. 7.

9. **Depth of Hold.**—This is measured from the top of the ceiling in vessels with ordinary floors, or from top of ceiling on double bottoms, if ceiling is laid; or from the tank top plating when no ceiling is laid, to the top of the beams of upper, spar, or awning decks. This is also the **Registered depth** (about 2½ in. is the usual allowance for ceiling).

10. **Extreme Proportions.**—A vessel is said to be of extreme proportions when her length exceeds eleven times her depth (moulded depth plus camber). Under such circumstances, additional longitudinal strength is required over and above that necessary when of ordinary proportions.

CHAPTER V.

STRESS AND STRENGTH.

Preliminary.—Forces exerted upon Ships—Water Pressures—Pressure per Frame Space—Estimated Pressure upon a Bulkhead and Centre of Pressure—Pressure upon a Tank Top—Tendency to Transverse Deformation—Longitudinal Stresses in still water and Tendency to Longitudinal Deformation—Bending Moment on a Loaded Bar—Possible effect of a bad disposition of Weights in a Ship—Longitudinal Stresses in Wave Water and Tendency to Longitudinal Deformation—Local Stresses, Panting Stress, Stress due to Propulsion by Steam, Stress due to Propulsion by Sail, Stress caused by loading Heavy Cargoes on deck and the shipping of Heavy Seas, Rudder Stresses, Strains from loading aground, Stresses upon Vessels which are temporarily only partially waterborne, Launching Stresses—Stress and Strain—Ductility and the Elastic Limit—Moment of Inertia—Curve of Loads—Curve of Shearing Stresses—Curve of Bending Moments—Stress per Square Inch—The Equivalent Girder—Computation of Moment of Inertia of Compound Girder—Stress per Square Inch upon Upper and Lower Surfaces of foregoing Girder—Bending Moment of an actual Ship ; Curve of Weights, Curve of Buoyancy, Curve of Loads, Curve of Shearing Forces, Curve of Bending Moments—Moment of Inertia of Actual Ships—Comparison of Vessels—Disposition of Material—Effect of Modification in Depth of Transverse Frames—Value of Stress Calculation—Calculation for Position of Neutral Axis and Moment of Inertia of an Actual Ship—Estimate of Bending Moment for an actual Ship, and Stress per square inch—Value of Registration Societies to Shipowner—Comparison of Stresses on Vessels increasing in size—Further Remarks upon the Value of Stress Calculations—Working Stress—Erections on Deck—Board of Trade Instructions for Comparing the Strength of Vessels for Freeboard Purposes—Deductions—Calculation to find Neutral Axis—Calculation of Moment of Inertia of a Vessel when supported upon Wave Crest at Middle of Length, and thus subject to Hogging Stresses.

Preliminary.—Having become acquainted in the previous chapter with the general structural features of ships and the usual disposition of both longitudinal and transverse framing, it follows in the natural order of things in traversing the wide area of the field of ship construction, that at the outset it is of the highest importance that a comprehensive knowledge of the numerous and severe stresses which ships have to endure under varying circumstances in following their various trades be possessed. And not only should the strength of individual pieces of steel or iron when subject to tensile, compressive, torsional or shearing stresses be fully understood, but the strength value of girders and combinations of girders variously disposed, such as are found in the structure of ships, should be comprehended. Indeed, without such knowledge as this, it is absolutely impossible to intelligently determine the structural arrangement of ships, so as to obtain anything like the highest degree of efficiency.

The stresses to which ships are subject are usually classed under three principal heads, and arranged in order of their importance as follows:—

I. Longitudinal Stresses.
II. Transverse Stresses.
III. Local Stresses.

However, although it is intended to observe and enumerate the chief stresses which come under each of these divisions, to adhere rigidly to this order in dealing with them is neither necessary nor advisable.

It was pointed out in an earlier chapter, that when a vessel is classed at Lloyd's, or with any other classification society, the responsibility of structural strength and efficiency of the workmanship is borne by the society in question. Their special work is to consider the numerous and varied stresses to which ships are liable in smooth and wave water, and to specify in their rules the nature and disposition of material to ensure against structural damage arising as the result of the continuous or occasional presence of these stresses, when vessels are properly, or rather, intelligently loaded and ballasted.

These societies, however, whose business is conducted and superintended by men of great scientific and practical experience, are always willing to accept, and substitute, any proposed mode of construction, providing that its efficiency is equal, or superior, to that prescribed in their rules.

A huge accumulation of material does not ensure a strong vessel, and therefore the most heavily constructed ship is not necessarily the best. Ships are not built to be marvels of ponderous massiveness, strength, or weight. Far from it. Cargo or merchant ships are built to earn money, and in these days of keen competition, economy in design, in working, and in maintenance, are primary considerations to every shipowner. The lightest ship is therefore the best ship, that is, if she possesses sufficient strength for the demands which will be made upon her in carrying her maximum load in all the probable conditions of weather she will experience.

Every ton of unnecessary iron, or steel, or wood, or other constructive element in the ship, means a ton less freight, and reduced earning power. Too much attention, therefore, cannot be given to the careful study of every detail in the design, and the alternative modes of construction.

Forces exerted upon Ships.—It is thus proposed at this stage to consider, as briefly as is consistent with clearness, the varying forces which exert themselves upon ships, and to observe the nature of the resistance which the structure, as a whole, offers to deformation and fracture.

Water Pressures.—To attempt to dispose of the structural material in a vessel, before fully comprehending the nature and magnitude of the various stresses which are experienced, could only result in most imperfect design and misplacement of strength.

To those who have given little consideration to this aspect of the subject, many peculiar and sometimes amusing ideas present themselves as reasons why ships float. But, on careful investigation, there is nothing mysterious after all. All ships, no matter what their weight may be, are subject to the same gravitation influence as all other structures, and, like them, have to be supported if they are to maintain a condition of equilibrium. Thus, if it were possible to suspend a ship weighing, say, 2000 tons, on a spring balance, in mid air, and slowly lower her into the water, we should find that on first touching the surface she would still weigh 2000 tons. But immediately she began to be partly immersed, the balance would register an alteration in the weight, decreasing gradually in a proportion strictly in accordance with the amount or volume of immersion from 2000 tons down eventually to nothing, when the ship would remain stationary, with not the least tendency to become either more or less immersed. Indeed, she now offers determined resistance to any alteration in draught so long as neither additions nor deductions are made to her original weight. Though the balance registers 0 tons, reason forbids our assuming that the ship has decreased in, or lost, weight. What it does prove is, that the balance has gradually been relieved of, or freed from, the effort of supporting the original 2000 tons, the support having been gradually obtained from an evidently upward pressure from the water, which increased as the ship continued to be further immersed, until it was able to support the whole of the 2000 tons, at which moment the balance showed 0 tons.

So that when we talk about a ship floating, we simply mean that she is being supported by the water. To balance this ship in mid air by means of supports, say, pillars of iron, would be no easy matter. A ship is a huge, bulky object; her weight is enormous, and a very careful estimation of the strengths of the supports, and their number and positions, would have to be made in order to safely effect this. But in water, the support and balance are perfect. There are exactly 2000 tons of upward pressure from the water to exactly support the 2000 tons downward pressure of the weight of the ship, the balance being perfectly effected by the centre of the support (or the resultant of all the supports) termed the Centre of Buoyancy, and the centre of the weight, termed the Centre of Gravity, being exactly in the same vertical line, which condition is absolutely essential in order to preserve an exact balance, or, as we say, equilibrium. The net result is, that we have two equal and opposite forces exactly neutralizing each other, and producing no result whatever.

A ship, or any object capable of floating, on being launched, or by any means placed in water, immediately, by these natural laws, places herself in a position such as we have described; indeed, she must do so before a condition of rest can be maintained.

We have seen that any object floating in water is supported by the pressure or thrust, derived from the water itself. Upon every part of the immersed surface of a floating object, the pressure is exerted in lines of action perpendicular to the surface. This is indicated in diagram 15 by the lines of water pressure, in the various immersed, or partially immersed objects.

As the direction in which water pressures exert themselves is of very great importance in determining the structural strength of immersed, or partially immersed objects, a little experiment, confirming the preceding statement that they act in lines perpendicular to the surface immersed, will be of interest.

Suppose a vessel of the form shown in diagram 16, perforated all over its surface with small holes, to be filled with water. It would be found that the water would squirt out of the holes in directions perpendicular to the surface of the vessel at each part, thus indicating that the pressures on the internal surface of the vessel are perpendicular to the surface acted upon. See fig. 16, A, page 56.

Or again, suppose the same vessel to be suddenly immersed in water. In this case, water would squirt into the vessel in directions perpendicular to the surface, thus again proving that the external pressures are exerted in lines perpendicular to the immersed surface. See fig. 16, B.

Figs. *a*, *b*, *c*, *d*, *e*, *f*, and *g* on the next page will enable us to make a simple analysis of these forces, and in some degree estimate their amount.

First, then, we will take fig. *a*. This is a rectangular box vessel, whose bottom surface has an area of exactly 1 sq. ft., the height of the box being, say, 2 ft. 6 in. Let the water in which this vessel has to be immersed be fresh water. The box is so weighted as to produce a total weight of 62½ lbs. On placing the box in the water, we should find that it would sink until its draught, or immersed depth, is 1 ft., proving that at no less depth or draught was there 62½ lbs. of upward pressure from the water. As all water pressures act perpendicularly to the immersed surface, only those on the bottom of the box act vertically, the others on the sides acting horizontally. The horizontal pressures afford no support whatever, their force being only exerted to crush in the sides of the vessel. The whole of the pressure for the support of the vessel is therefore provided by the vertical pressures on the bottom of the box, and their total pressure must equal 62½ lbs. in order to support the 62½ lbs. of weight of the box. This upward pressure is termed *buoyancy*. Now these upward pressures upon which a floating object depends for its maintenance upon the surface of the water, increase in force in direct proportion to the depth from the surface. This we can easily prove. Suppose another 62½ lbs. be placed in the box vessel, *a*. We should find, instead of the depth of immersion remaining at 1 ft., that it had increased to 2 ft. exactly, as shown by fig. *b*.

That is, the same area of bottom surface is exposed to exactly twice the amount of pressure; and so on, the pressure increasing proportionally to the depths of immersion.

Thus the *total* area of immersed surface has *no* relation whatever to the *amount* of support given.

Fig. *b* has not twice the total immersed surface of fig. *a*, though the draught is exactly twice as much, but it (*b*) certainly experiences considerably more than twice the total pressure upon its total immersed surface.

Owing to the increase in pressure with increase in draught, we have seen that on *b* there is twice the upward pressure on the bottom. Then the sides of *b* for 1 ft. down have the same external pressure as in fig. *a*, but for the second foot down, the pressure is twice as great as on the sides for the upper foot. To sum up, therefore, the bottom of *b* experiences twice as much upward pressure as the bottom of *a* and the sides four

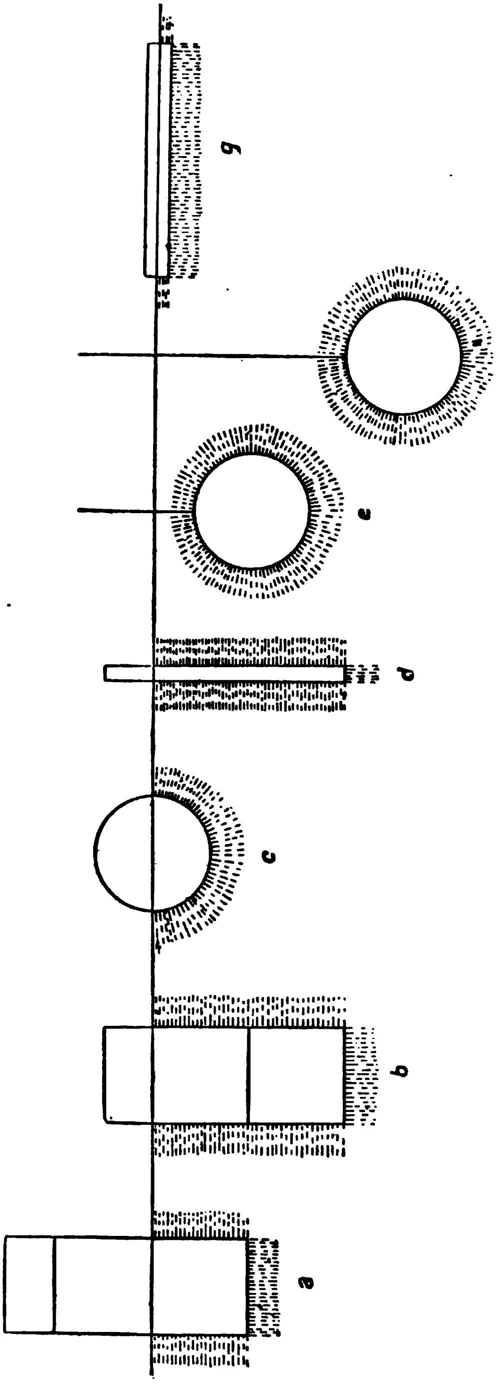

FIG. 15.—Water Pressures upon Immersed and Partially-immersed Objects.

times as much. This will be made clear by fig. 17 and the accompanying notes.

The ratio of the increase in these horizontal pressures is most important, for they show that on such a surface as a watertight bulkhead to a peak tank, or a deep ballast tank, in order to get maximum efficiency, the distribution of strengthening materials should not be made uniformly over the area of the bulkhead, but rather in accordance with the stresses endured locally over the bulkhead owing to the water pressures. Did area of immersed surface regulate the amount of *support* afforded by the water, then such an object as *d*, fig. 15, ought to have exceptional support. But this is not so, for the only support is again from the vertical pressures, which have a very small area upon which to exert themselves, and consequently, in order to receive the support necessary, a considerable depth has to be reached. Had the same object been placed horizontally in the water as in *g*, fig. 15, then, though the total immersed surface would be greatly reduced, yet the much greater surface exposed to vertical pressure would require only slight immersion in order to obtain the amount of support necessary.

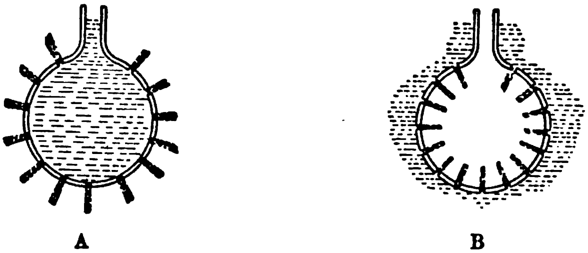

Fig. 16.—Water Pressures.

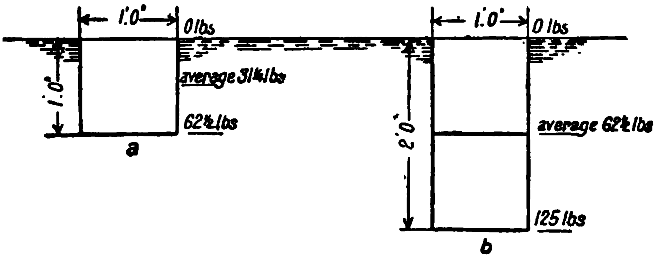

Fig. 17.—Total side pressure upon a = 1 sq. ft. × 4 sides × 31¼ lbs. = 125
,, ,, ,, ,, b = 2 ,, ,, × 4 ,, × 62½ ,, = 500

Thus, in two vessels of different proportions but equal displacements, the one whose draft is greatest will experience most crushing pressure on its external surface.

Fig. 15, *c*, shows the nature of the pressures upon a cylindrical object floating in water. Here, although all the pressures are perpendicular to the immersed surface, yet only a small proportion are truly vertical and horizontal. The others are more or less oblique, and afford support in proportion to the degree of vertical tendency they possess, so that the *resultant* of all the upward pressures is equal to the weight of the cylinder. The *total of the external* pressures experienced in this case also, represent a force exceeding the weight of the cylinder.

Fig. 15 *e* is a spherical object suspended as shown, its weight being such that the water pressures are incapable of supporting it in any partially immersed condition. The result is that it would sink. But if it is true that the vertical pressures increase with the depth, surely it ought to be able to receive a sufficient support at some definite depth below the surface. At any rate, this is sometimes the reasoning of younger students. But suppose the sphere is allowed further immersion, as in *f*, we shall see that it has really received no more ultimate support than at *e*. In these cases, where there is total immersion, we have vertical pressures downwards upon the upper surface of the sphere, as well as upwards on the lower surface, and thus, just in the same proportion as the upward pressures increase with depth, the downward pressures increase for the same reason also. There is therefore no position of equilibrium for totally immersed objects between the surface and the bottom of the water, unless, as in the case of submarine vessels, some means exist for increasing the displacement, or of propelling the vessel vertically.

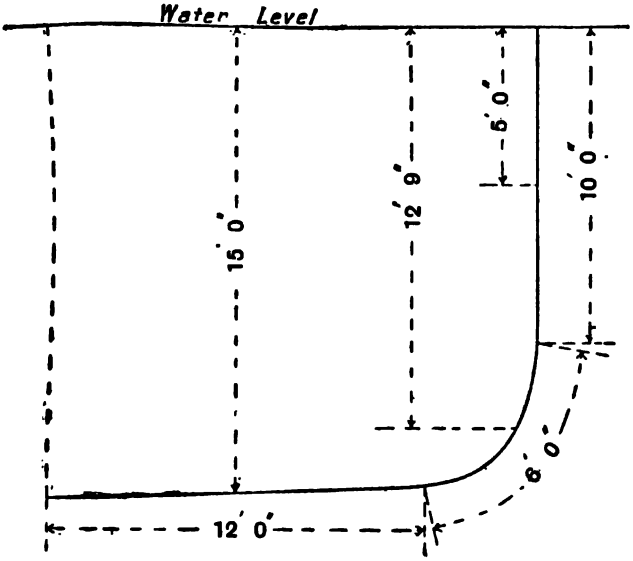

FIG. 18.—Diagram illustrating the Calculation for amount of Water Pressure on a single Frame of a floating Vessel.

Thus, on account of this increasing pressure as greater depths are reached, objects which could easily endure the external pressure at or near the surface, collapse entirely at greater depths from the excessive crushing strain experienced. While fresh water exerts a vertical pressure of 62½ lbs. per square foot at 1 ft. depth, sea water (salt) registers 64 lbs. owing to its greater density.

Pressure per Frame Space.—But suppose the designer of a vessel, in considering the strength of the transverse framing, is desirous of knowing the amount of water pressure upon the area of the space between any two consecutive frames, or, what amounts to the same thing, the amount of pressure per frame, the result may be arrived at in the following manner.

Let fig. 18 represent a section of the vessel up to the water level at which the pressure is required. Assume the frames to be spaced 2 ft. apart. Divide the half girth, which is 28 ft. from keel to waterline, into divisions similar to those shown in the fig. As the pressures increase in direct proportion to the depth, the pressure in lbs. upon the area of each division is found by multiplying its area in square feet by 64 lbs. (salt water), and this product by the distance of its centre of gravity below the water level.

The calculation would be as follows:—

Spaces.	Areas sq. ft.	lbs.	Distance of C.G. below water level. ft.	lbs. pressure.
2′ × 10′	20	64	5·00	6,400
2′ × 6′	12	64	12·75	9,792
2′ × 12′	24	64	15·00	23,040
			Pressure upon one side of vessel =	39,232 lbs.
				2
				78,464 lbs. pressure upon whole frame space for both sides.

Estimated Pressure upon a Bulkhead and Centre of Pressure.—Or again, suppose it is desired to determine the amount and distribution of the pressure upon a bulkhead, assuming that a compartment be perforated, and partly, or just filled with water; and also how to apportion the structural strength to best withstand such pressure.

Let fig. 19, *a*, represent the front elevation of the bulkhead up to the height to which the water has risen. Being rectangular, the centre of its area is obviously 6 ft. below the top. Then the total pressure upon the bulkhead is $10 \times 12 \times 64 \times 6 = 46{,}080$ lbs.

But as we have seen, the water pressure increases directly in proportion to the depth. The distribution of this pressure can be illustrated as follows:—

Let A B (*b*) represent the bulkhead in section. Make B C equal to A B, or, for the matter of that, it may be drawn to any scale. Join A C. It follows that all horizontal lines from A B to A C will be proportional to the pressures at the various depths. The area of the triangle of pressure A B C represents the total pressure upon the bulkhead A B, and its centre of gravity represents the vertical height of the '*centre of pressure*' upon the bulkhead, or the point at which the bending moment upon the bulkhead attains its maximum. In the case of a triangle, the centre of gravity is at one-third the height from the base, hence the centre of pressure is situated 4 ft. from the bottom of the bulkhead. The shearing stresses, on the other hand, increase with depth, and therefore reach a maximum at the lowest depth, or, in other words, at the bottom of the bulkhead.

Theoretically, the structural strength arranged vertically on a bulkhead should gradually increase in dimensions down from the top to the point at which the bending moment reaches its maximum (at the centre of pressure) and be again reduced towards the bottom. Similarly, structural strength arranged horizontally should be distributed in the same manner. In actual practice, however, as shown in Chapter VII., theoretical deductions often require modification. It will be obvious, however, how essential it is that the structure of the bulkhead be firmly secured at its bottom extremity. How this is done we shall see more clearly when we come to deal with the actual structure of bulkheads.

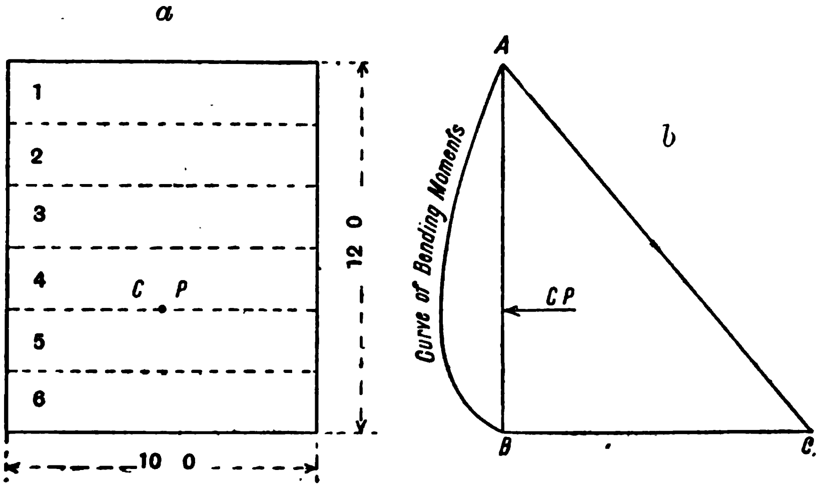

FIG. 19.—Pressure upon Watertight Bulkhead.

In the case of an actual ship bulkhead which is not absolutely rectangular, the calculation for centre of pressure would be arranged as follows:—

First divide the bulkhead into a number of parallel areas of equal breadth, as shown in fig. 19, each in this case being 2 feet wide. Next, determine the number of square feet in each area, and the distance of its centre of gravity below the top of the bulkhead. Then find the pressure upon each area, and finally, the centre of the application of the whole of these pressures, thus :—

No. of Area.	Area sq. feet.	Lbs.	Distance of Centre of Area below Top of Bulkhead. Feet.	Lbs. Pressure (Product of last three Columns).	Approximate Leverage for Moments. Feet.*	Moments: foot lbs. (Product of last two Columns).
1	20	64	1	1,280	1	1,280
2	20	64	3	3,840	3	11,520
3	20	64	5	6,400	5	32,000
4	20	64	7	8,960	7	62,720
5	20	64	9	11,520	9	103,680
6	20	64	11	14,080	11	154,880
				46,080	46,080)	366,080

Centre of Pressure below top of Bulkhead =7·94 ft.

The result is nearly 8 feet, practically $\frac{2}{3}$ depth down from top of bulkhead.

Pressure upon a Tank Top.—As further illustration of water pressure, take a water ballast tank, filled to its utmost capacity by means of a pump whose discharge pressure is, say, 10 lbs. per square inch, and no means of escape provided.

Supposing the tank be 30 feet long and 20 feet wide, and pumping to proceed after the tank is full, the pressure upon the top of the tank will amount to 10 lbs. per square inch, or upon the whole surface :—

$$\frac{30 \times 20 \times 144 \times 10}{2240} = 385\frac{5}{7} \text{ tons.}$$

Or, to take another example, suppose that a pipe of, say, 1 square inch sectional area, 20 ft. long, and open at the top end, be placed vertically in the top of a double bottom tank, and that water be pumped into it until it overflows at the upper extremity of the pipe. The pressure at the bottom of the pipe would be equal to the weight of water in the pipe $= \frac{20 \times 12}{1728} \times \frac{62\frac{1}{2}}{1} =$ 8·7 lbs. (fresh water taken), that is, the pressure upon the inner surface of the top of the tank is 8·7 lbs. per square inch, or, upon an area 20 ft. by 20 ft. the pressure would be $\frac{20 \times 20 \times 144 \times 8{\cdot}7}{2240} = 223{\cdot}7$ tons.

This is the method usually adopted in testing the watertightness and general efficiency of cellular, deep, and other tanks.

The value of sufficient and properly disposed air pipes, apart altogether from any consideration of ventilation, will be obvious, and the possibility of causing damage to an inner bottom or other tank top, through pumping up these tanks with air pipes closed, and no other means of exit for air or overflow water, will also be apparent.

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* The horizontal strips being taken narrow enough, this approximate leverage is sufficiently accurate for practical purposes.

Tendency to Transverse Deformation.—Having shown by the foregoing examples the mode of calculating the amount of pressure upon an immersed surface, it is proposed to illustrate, by the following series of sketches (figs. 20–24), the *tendency* to deformation of transverse form in the hulls of ships caused by these pressures, as well as by other crushing forces which are experienced under varying circumstances. It should be understood, however, that though the tendency of any such deformation as may be illustrated undoubtedly exists, yet in a well-constructed vessel, such tendency never betrays its existence, simply because the structural strength has been intelligently distributed to resist it, that is to say, to render it practically imperceptible.

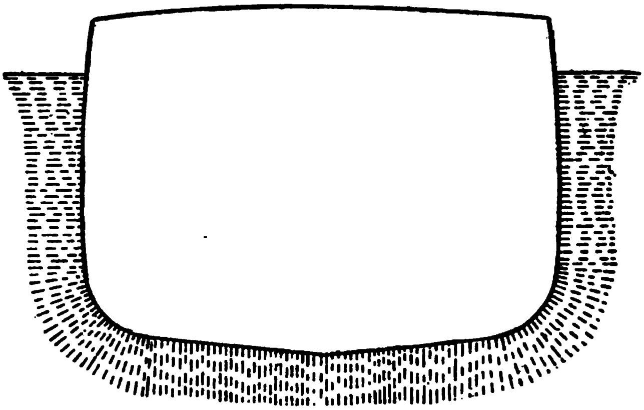

FIG. 20.—Showing direction of Water Pressures upon Immersed Hull of Ship.

Here the transverse form of the vessel floating in an upright condition is shown, and upon its immersed surface are indicated the lines of water pressures.

The resulting tendency, owing to the application of the afore-mentioned pressures (see page 54), is illustrated in fig. 21. To resist such deformation, the vessel must have efficient transverse girders or frames, and especially so along the bottom where the pressures are greatest. The topsides are kept in place by the beams, which are connected to the frame heads, and act as both struts and ties. The strength to the sides is assisted at intervals of the depth by transverse struts in the form of tiers of beams. The bottom is stiffened by means of deep transverse floor plates placed vertically (usually on every frame), which are further assisted by the keelsons, and by being tied to the decks by means of the pillars, numbering at least one in the breadth.

In fig. 22 we see the same transverse section of the vessel subject to the same water pressures, but, in addition, it is supposed that a severe local stress is caused by the concentration of some very heavy deadweight such as cargo of great specific gravity; deep water-ballast tanks; engines, boilers, and bunkers (especially in a light ship). The tendency is to elongate the vessel vertically, and to cause the insufficiently supported bottom to droop; while the tendency for the topsides to contract causes the deck to spring in the middle. Resistance is offered to such deformation by the same transverse framing as enumerated for fig. 21, assisted by the same longitudinal girders. Here, especially, is seen the great value of pillars acting as ties, binding together the top and bottom of the vessel, and hold-

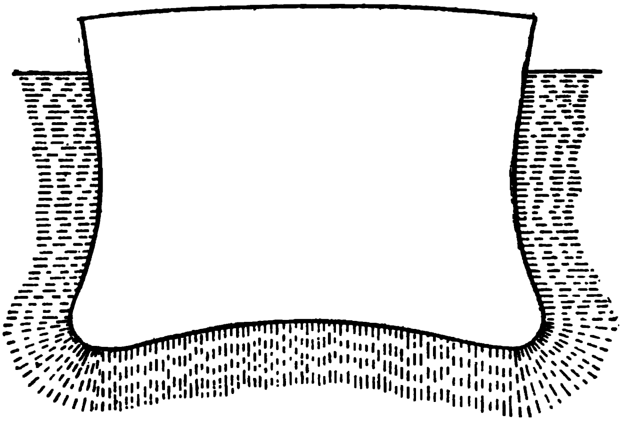

FIG. 21.—Tendency to Transverse Deformation due to Water Pressures.

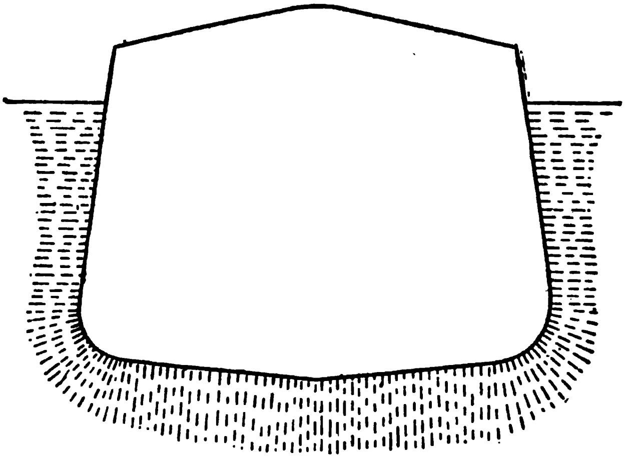

FIG. 22.—Showing tendency to produce Vertical Elongation.

ing the beams and floors in their true relative positions. The value of efficient means of connection between the side framing and beams, and side framing and floors in the form of webs, will also be very evident.

Neglecting the tendency to deformation caused by the water pressures, in fig. 23 we have assumed the deck to be subject to a heavy weight placed upon it, producing the tendency to droop at the middle. On most vessels there is considerable deck weight in the form of winches, windlass, houses, bollards, and other deck furniture. In addition, many vessels carry very heavy deck cargoes in the form of timber, etc. But apart from intentional deck loads, huge heavy seas are sometimes shipped upon deck, producing enormous and sudden stresses, which, even in large new vessels, built to the highest class, have been known to sheer the rivets in the beam knees, damage the hold stanchions, carry away hatch coamings, and effect other damage, in addition to producing considerable sinkage in the deck, as illustrated in the above figure.

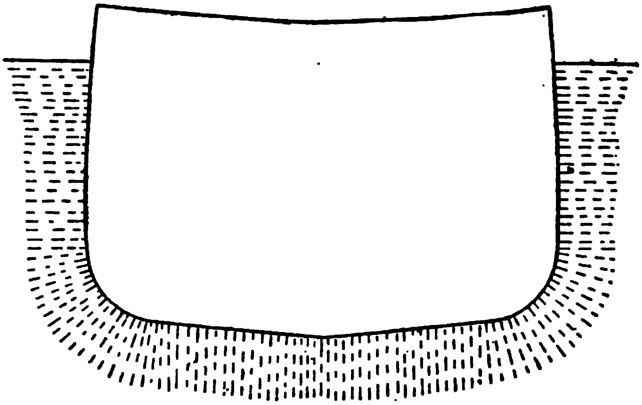

FIG. 23.—Showing tendency for deck to sag at the middle, owing to heavy Deck Weights or Shipped Seas.

The principal structural parts resisting such deformation as described, are deck beams connected to the side framing by efficient knees well riveted, and supported by thoroughly efficient pillars well connected at heads and heels.

In fig. 24 the same vessel is supposed to be subject to violent rolling in wave water, which movements, aggravated by the inertia of cargo in the holds, or water in large ballast tanks, tend to severely rack the transverse form of the vessel, and to produce such distortion as illustrated. To prevent this deformation, the localities where such working is most likely to be experienced—viz., at the junction of the uppermost deck with the sides, and at the bilge—should be well strengthened. This is done by making the connection between the beams and the side framing by webs of plating (knees), and connecting the floors to the side framing by similar, but larger webs,—turned up floors in the case of ordinary floors, and brackets where double bottoms are fitted. See figs. 6 and 7.*

There are certain other severe local stresses, chiefly affecting the transverse form, to which ships are sometimes subject. These, however, are generally the result of ignorance on the part of those responsible, and neither the naval architect nor the rules of any classification society pretend to fully provide for them.

The first of these is the case where a vessel is in dry dock with an insufficient number of blocks supporting the keel. Consequently enormous pressure is experienced on the bottom in the way of each block, with the accompanying tendency to crush in the bottom and produce great distortion locally in the transverse form, and serious damage to the bottom.

The second is that of a vessel in dry dock, when an ample number of blocks has been placed under the keel, but insufficient support afforded at the bilges owing to the bilge blocks being too widely spaced. Here the tendency is for the bilges to droop. Such straining is all the more severe and complicated when the vessel has cargo in the holds, or, in addition to the weight of the engines and boilers, side or cross bunkers are full, or deep water-ballast tanks happen to be full. An approximation to the amount of the transverse bending moment may be obtained by multiplying the weight (W) in any locality on one side between the keel and side, by the distance of its centre of gravity out from the centre of the keel (x).

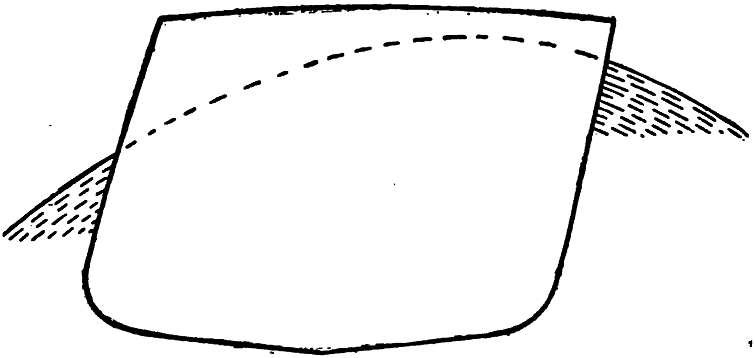

FIG. 21.—Illustrating tendency to deformation due to Racking Stresses.

$W \times x =$ bending moment.

And lastly, wherever there is very excessive preponderance of weight over buoyancy, or buoyancy over weight, in any locality in a vessel, though the effect may not be to produce a longitudinal bending moment, yet it tends to produce local bulging.

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* Transverse complete or partial bulkheads in holds and 'tween decks, in addition to providing excellent support to the longitudinal framing, are of great value in resisting such deformation as is liable to be produced by severe transverse racking stresses.

Longitudinal Stresses in still water and Tendency to Longitudinal Deformation.—While such stresses as illustrated from fig. 20 to 24 may be very severe both in smooth and wave water, they are probably the most easily provided against in the construction of a ship. They are known as '*Transverse Stresses.*' When we come to deal with fore and aft, or longitudinal stresses, much more difficulty, however, is experienced.

In fig. 25 we have a longitudinal elevation of a ship floating in smooth water, at the water line indicated. The stresses borne by the hull in consequence of the water pressures on every part of the immersed surface, tending to crush in the bottom, sides, and ends, are unavoidable. But even though lying motionless upon the water, it is quite possible that other stresses of considerable importance may exist.

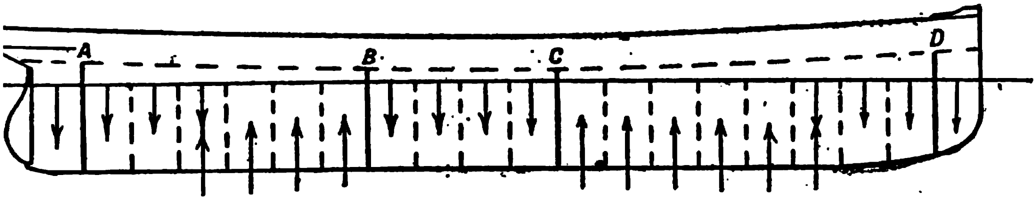

FIG. 25.—Diagram illustrating the excesses of Buoyancy and Weight at intervals throughout the length of a vessel in a *light* condition.

Upward arrowed lines represent buoyancy in excess, and downward arrowed lines represent weight in excess. Where both arrowed lines appear, the weight and buoyancy are equal. The thick vertical lines A B C D represent bulkheads. The space between B and C = engine and boiler space. The spaces between A B and C D = cargo spaces. *Note.*—The draught on the diagram has been exaggerated, in order to more clearly illustrate the weight and buoyancy by means of the arrow.

Let fig. 26 be a box-shaped vessel which, though drawn to a smaller scale, is supposed to be of the same extreme dimensions as fig. 25. We will assume that the weight of the cargo taken on board has been uniformly distributed throughout the length, thereby producing no alteration to the trim. Then the uniform upward pressure of water along the bottom of the vessel is exactly counterbalanced by the uniform downward pressure of weight throughout the length. Such uniform counterbalance of forces does not produce any stress tending to longitudinal deformation.

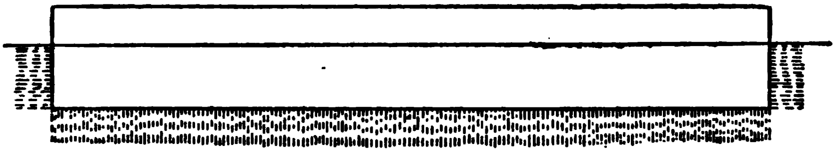

FIG. 26.—Box-shaped vessel uniformly loaded all fore and aft with weight and buoyancy exactly counterbalancing each other. No tendency to deformation in a longitudinal direction exists.

But on returning to our actual ship in fig. 25, no such uniformity is found. If it be assumed that the ship floats *light*, we find considerable difference between the buoyancy and the weight locally throughout the length, though for a ship, as for every other floating object, the law must hold good that the *total* weight and the *total* buoyancy equal each other. Thus, at amidships, or wherever the engines and boilers are situated, there is a great concentration of weight, and in many cases this is increased by the erection of bridges, houses, etc. Then, again, at the ends of vessels there is usually a concentration of heavy weight. At the fore end there is often a forecastle, also the anchors, chains, windlass, solid iron stem bar, anchor crane, heavy mooring arrangements, and in addition, special stiffening to prevent 'panting' (see page 72). At the after end a poop is often built. A heavy solid steel or iron stern frame, propeller, tail end shafting, steering gear, mooring arrangements, etc., are also found in this part.

Turning from weight to buoyancy, we see where and how the difference previously mentioned arises. Wherever we have greatest immersed bulk, we have greatest buoyancy, simply because where there is this bulk there must be in some shape or other a large surface exposed to the upward or buoyant pressures. Hence, keeping before our minds the usual form of a vessel's immersed hull, we see that the greatest buoyancy is at amidships, and, in cargo vessels, this may extend for a considerable proportion of the vessel's length, with practical uniformity, fore and aft of midships. As the ends, however, are approached, a rapid change of form is observed as the vessel fines down towards the stem and stern, causing an enormous reduction in immersed bulk, and hence in buoyancy. Thus, in traversing the length especially of a steam ship (see fig. 25), we are struck by the unequal distribution of the weight and the support, or buoyancy. The heavy after end has little and most inadequate support from the water, owing to the fineness of its underwater form. But as we come forward to the hold space the ship rapidly increases in fulness, and is, moreover, comparatively free from exceptional weight. The consequence is that the buoyancy rapidly increases, and is eventually in excess of the weight. At amidships, where the machinery is situated, the weight is again in excess of the buoyancy in a light ship. Forward, similar conditions to those found at the after end exist. At first, after leaving the machinery space, when the heavy engines and boilers are amidships, the buoyancy is considerably in excess of the weight, then it gradually diminishes as the vessel fines down, until eventually the weight of the fore end preponderates considerably over the buoyancy. Thus throughout the length of a ship, a series of stresses are experienced which *tend* to strain and produce deformation in the longitudinal direction.*

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* When a bar, loaded at each end, and supported at the middle of its length, droops towards the ends owing to the bending moment experienced, the visible deformation produced is popularly termed 'hogging.'

When the bar is supported at each end, and loaded at the middle of the length, causing the bar to droop in way of the weight, the visible deformation produced is popularly termed 'sagging.'

While it is owing to the existence of great excesses of weight over buoyancy, or *vice versâ*, throughout the length of a ship, that longitudinal bending moments are created, tending to produce longitudinal deformation, it must not be imagined, as shall be shown, that *every* such excess necessarily produces a corresponding longitudinal bending moment. For instance, a small excess caused by an isolated concentration of weight in the middle, say, of a huge bulk of excess of buoyancy would not necessarily produce a longitudinal bending moment, though the proportionately small excess of local weight would certainly tend to produce local bulging.

Let fig. 27 represent a vessel floating in a light condition with, say, engines and boilers situated amidships, bunkers full, and a large peak ballast tank at each end full. If the holds were completely empty, it is clear that in an ordinary cargo vessel the greatest excesses of support over weight would be in way of the two hold spaces. The excesses of weight over buoyancy at the ends and amidships, owing to the peak water-ballast tanks and the machinery and bunkers, at first incline one to conclude that considerable straining will in consequence be produced towards the ends and in the region of amidships, and 'sagging' in these localities possibly ensue.

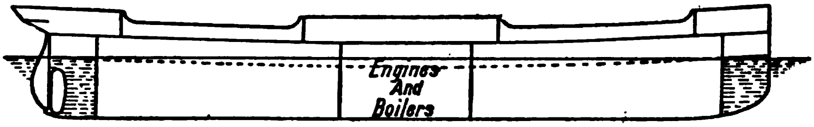

FIG. 27.—A small Steam Vessel with fore and after peak tanks full, and bunkers full.

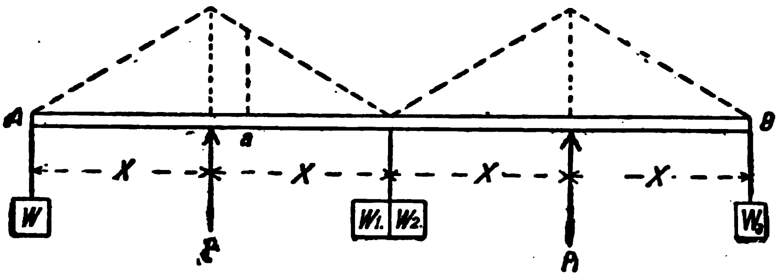

FIG. 28.—Showing the nature of the bending moments upon a bar loaded somewhat similarly to the ship in fig. 27.

Bending Moment on a Loaded Bar.—But let us consider the same features in a simpler form (see fig. 28).

Let A B be a bar of the same length as the ship. W and W_3 are weights suspended at the ends, representing, in some measure, the peak ballast tanks, and W_1 and W_2 (one weight) at the middle of the bar, representing the weights of machinery and bunkers. Let the supports P and P_1 be placed midway between the middle and the ends of the bar.

Now W, W_1, W_2, and W_3 are by hypothesis, in this case, supposed to be equal to one another in value, and, instead of the double weight W_1 and W_2 producing a 'sagging' moment at the middle of the bar, no bending moment whatever exists there.

Suppose the bar to be perfectly rigid all fore and aft. The pressure upon P will be equal to the weight of $W + W_1$ and the pressure upon the support P_1 will be equal to $W_2 + W_3$.

Not only are the pressures on the supports exactly equal to the weights, but they exactly poise their respective weights in equilibrium, W and W_1 each being χ distance from P, and W_2 and W_3 each being the same χ distance from P_1.

The bending moments, therefore, instead of being greatest at the middle of the bar, are greatest at the points of support P and P_1, where they are $W \times \chi$. This quantity being set off to any arbitrary scale of moments above the bar at the point of support, and the point so obtained joined to the ends of the bar (see dotted lines), a graphic representation of the bending moment on the beam is produced. A similar maximum bending moment would have been obtained by $W_1 \times \chi$, or $W_2 \times \chi$, or $W_3 \times \chi$. Or again, for the sake of example, the same result will be got by taking the moments up and down about any other point, say A.

Bending moment about A =

$$\{(W \times \text{no distance}) + (W_1 + W_2)\, 2\chi + (W_3 \times 4\chi)\} - \{P\chi + (P_1 \times 3\chi)\}$$

In like manner, the actual bending moment at the point '*a*' could be found by taking the algebraic sum of the moments up to, or about any point in the bar, or even outside of the bar.

The moment of any force acting upon the bar at any point is obtained by multiplying such force by the distance of its line of action (or position of its centre of gravity) from such point.

From the foregoing example, it is further evident that had the weight $W_1 + W_2$ been greater than either twice W or W_3, there would have been at the middle of the length a stress tending to a perceptible 'sagging' moment, and that had $W_1 + W_2$ been less than either twice W or W_3, there would have been a 'hogging' moment over the whole length, tending to cause the beam to droop from the middle of the length towards the ends.

The more $W_1 + W_2$ exceeds twice either W or W_3, the further does the sagging moment extend on each side of the middle of the length of the bar before a hogging moment is experienced.

Possible effect of a bad disposition of Weight in a Ship.—But while a ship is a much more complicated object with which to deal than a bar, loaded and supported as described, and the nature of the actual bending moments more difficult to ascertain, because the loads and supports are more distributed and more complicated, yet the principles involved are identical, though a greater amount of labour is entailed in arriving at the results. It will, nevertheless, be obvious how enormously the longitudinal bending moments, even in smooth water, may be increased in the operation of ballasting and loading. For example, we have seen how little support is afforded to the fore and after ends of a vessel, the excess of the weight over the buoyancy of these parts practically hanging upon the superabundant buoyancy of the adjacent parts of the hull. Suppose, as is often the case, that a large peak tank is filled, capable of containing 80 or more tons of water, it can easily be imagined how the stress we have observed to exist may be greatly aggravated.

While, undoubtedly, the breaking of propeller shafts, which is so common among steamers in light or ballast conditions, is attributable in the majority of cases to the fact that they are under-ballasted with their propellers only partially immersed, and in bad weather are subjected to violent racing and sudden jerking and checking as the propeller blades strike the water, yet it is not at all unlikely that, in many cases, damage to shafting may arise from longitudinal bending or twisting caused by the enormous weights concentrated, often in ignorance, at the aftermost extremity of ships, and especially when, in addition, poops are used for heavy cargo or bunker coal.

While the tank in a continuous double bottom is capable of carrying a very large amount of water, its capacity throughout its length is generally governed by the form of the ship, and it is not therefore calculated to produce severe stresses in smooth water.

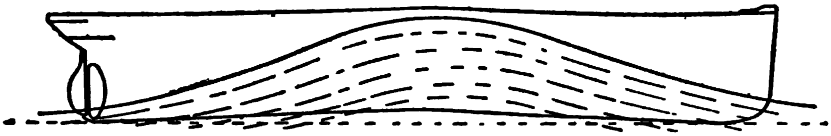

FIG. 29.—Showing *tendency* to 'hog.'

Then in regard to loading, it is evident that excessive straining would be produced by the disposing of heavy cargo where the buoyancy is naturally least.

Longitudinal Stresses in wave water and Tendency to Longitudinal Deformation.—Severe as such stresses as have been enumerated may be in still water, they only assume their true proportions when in wave water. Probably by the aid of the following diagrams showing a ship among waves we shall best be able, in a simple, graphic manner, to give prominence to the principal tendencies to deformation, which the longitudinal bending moments exert upon a ship's structure.

In fig. 29 we have a flush decked vessel supported at the middle of her length upon a wave, producing great excess of buoyancy at amidships, and increased deficiency towards the ends. Any vessel, waveborne in this manner, experiences her severest stresses on each side amidships. The tendency is, therefore, for the ends to droop, or as we say, for the vessel to hog. Sometimes, in looking along the gunwale of an old ship, and especially a wooden one, the drooping of the ends is distinctly seen, and the vessel is said to be hog-backed.

Fig. 30 represents exactly the reverse of the foregoing example. Here, each end of the vessel is supported upon a wave crest, and a great deficiency is produced in the buoyancy at amidships. In this case, the tendency is for the vessel to sag amidships, owing to the sagging moment experienced.

To resist such deformation as illustrated in the two foregoing diagrams, it is necessary that a vessel be of reasonable depth and possess a sufficient number of properly disposed longitudinal girders or frames. Thus along the bottom we find the girders, called 'keelsons,' varying in number and form with the size of the vessel. In all cases, whether these keelsons be fitted on the top of or between the floors, they should be well connected to the transverse framework.

Along the sides of the vessel somewhat similar girders are found, though no longer called 'keelsons,' but 'stringers.' These also vary in number and size according to the depth and size of the vessel. (See figs. 7 to 12.)

While it is necessary to cover the framing with a skin, the fact should not be overlooked that the shell plating forms an enormous contribution to the longitudinal strength. For example, each of the vertical sides, stiffened and prevented from buckling by the transverse framing, forms a huge girder in itself of very great strength, while these side girders are united, and the ship girder further strengthened by the bottom shell plating and decks. Stringers and decks render additional service in resisting longitudinal twisting when a vessel is crossing skew seas and rolling heavily. In considering the actual strength of a ship girder at a later stage, we shall see how additional strength is obtained by inner bottom plating in vessels with double bottoms, by steel or iron decks, and by longitudinal middle line bulkheads.

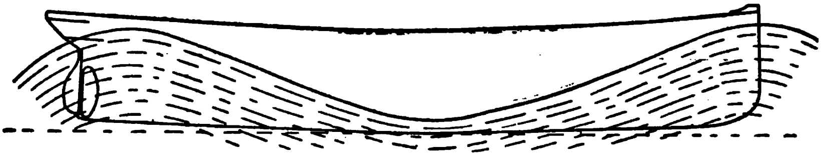

FIG. 30.—Showing *tendency* to 'sag.'

While it is often necessary to consider the structural values of the longitudinal and transverse framing independently, yet, how utterly dependent the one is upon the other for the fullest development of its efficiency, is easily seen. While strong, well constructed transverse watertight bulkheads are of great value from a safety point of view, in the event of perforation of the shell plating in way of any compartment, yet their value in stiffening the longitudinal framing and holding it to its work is of the greatest importance. This was especially illustrated in the case of the 'Great Eastern,' which was built upon the longitudinal girder system and contained very little transverse framing (see fig. 60, and Chapter VI.). This remarkable vessel depended in a great measure for her transverse strength upon the enormous strength of her well-arranged longitudinal framing, covered by an inner and outer watertight shell, assisted by numerous transverse bulkheads.

Then again, a vessel in a seaway does not always float in the upright condition, but often heels to very considerable angles of inclination, when a noticeable difference takes place in the structural resistance offered to the bending and twisting moments experienced, the stringers being called upon to perform in a measure the function of keelsons, and keelsons the function of stringers.

Fig. 31 illustrates a vessel with a poop, a bridge of some length, and a forecastle, supported upon a wave in the middle of her length. The stress experienced is similar to that in fig. 29, but the locality of likely damage resulting from the sudden reduction in longitudinal strength in the midship region is more marked.

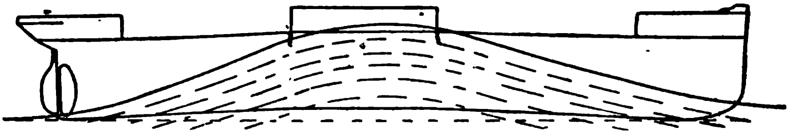

FIG. 31.—Showing *tendency* to fracture at ends of bridge.

The erection of a bridge, increasing the depth of the ship girder, adds greatly to the longitudinal strength of the ship over that part covered by the bridge, to resist damage (*i.e.* permanent deformation). But however valuable bridges may be, the sudden termination of these erections produces a weak section in the ship girder, which, unless specially provided for in some such manner as we shall observe at a later stage and when dealing more intimately with construction, would undoubtedly result in serious damage.

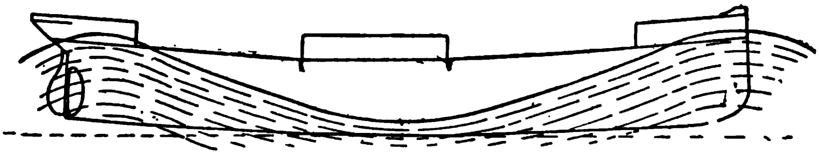

FIG. 32.—Showing *tendency* to buckle at ends of bridge.

Fig. 32 is similar to fig. 31, excepting that the vessel is now waveborne at the ends with the same *tendency to deformation*, due to the same cause as indicated in the previous example, fig. 31.

Similarly in vessels with raised quarter decks terminating somewhere on the middle length, without or with bridge houses to which they are connected (fig. 50); vessels with partial awning decks (fig. 51); or in vessels where the poop and bridge are combined (fig. 53); weakness in longitudinal strength caused by the sudden termination of such erections, necessitates careful attention to the structural arrangement at these parts.

Before any of the forms of deformation just illustrated could possibly be effected in a well designed ship, damage of a serious nature must have been wrought upon the structure. In a bad design, or in an old vessel, the nature of such damage would probably show most in the butts of the upper deck stringer plates and butts of topside plating (sheer strake, etc.) evincing signs of working, or opening, or in the rivets in these butts shearing, and, under exceptional circumstances, even these plates shearing through some line of rivet holes.

It is scarcely necessary to add that in the event of such damage as just described, the material must have been stressed far beyond its limit of elasticity, and if actual shearing of plates occurs, beyond the ultimate shearing strength. Damage of this nature could only arise through ignorance of the principles of loading, if the ship be well designed, or, where the vessel is properly loaded, to defective design combined probably with too light scantlings for the deadweight carried.

Local Stresses.—There are still several stresses, chiefly of a local character, which should be enumerated.

1. *Panting Stresses.*—These stresses are caused by the pressures upon the immersed fore end of vessels as they are propelled through the water, with the tendency to make this part work in and out in a manner resembling the action of 'panting'—hence the term.

It follows, then, that the higher the speed the greater will be the pressure, and the severer the stress. Small vessels of considerable speed with thin shell plating often show the result of this pressure by the plating between the frames bulging inwards. Bluff fore ends also expose a greater surface to such pressure.

All or part of the following means may be adopted to strengthen vessels to resist damage from such stresses:—Thicker shell plating with a closer spacing of transverse frames, deep floors, extra tiers of beams, and stringers, with large breast-hooks.*

2. *Stresses due to Propulsion by Steam.*—As already shown, there may be considerable inequality in the pressure of weight and buoyancy in way of the engines and boilers in certain light, load, and ballast conditions. But the most important stresses produced by the machinery in many vessels are those of vibration, though at the same time it must

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* In addition to panting stresses, a vessel is subject to severe thumping under the bows as she drives ahead, and dives into head seas. These stresses are likely to be most severe in vessels of high speed and at a light draught, especially if they be of full form under the fore foot, or 'club-footed'; as is the term in shipyard practice. These stresses have in some instances been so severe as to bulge in the frames and shell plating in the locality indicated. To prevent this and to afford the necessary stiffening, it is advisable that the frames be doubled from margin plate to margin plate in double bottom tanks and from bilge to bilge where no such tanks exist, for about one-fifth of the vessel's length from the stem, and, in addition, to fit intercostal plates between the floors forward of the collision bulkhead and extending well down on to the keel plate, and for such a distance forward towards the stem as the form of the vessel shows to be necessary. See figs. 46, 47, 49.

be remembered that vibration is not necessarily an indication of weakness, nor even that stresses are being endured. All bars, beams, and girders have their natural vibratory periods, and it is when the natural period of vibration of the engines (revolutions) coincides with, or synchronises with that of the ship girder, that vibration may become very prominent and dangerous.

The position of the machinery in a vessel may considerably influence the degree of vibration experienced, and therefore from this cause alone a strong vessel may suffer an unusual amount of vibration.*

Vibration may also be the result of weakness in the ship structure, and when this is the case, measures should immediately be taken to stiffen up the hull and add the necessary strength.†

Excessive vibration from whatever cause should receive careful attention, for its continuance must ultimately seriously strain the structure, and tend to loosen rivets and open butts and produce leakage. To provide against this, the following precautions may be adopted: additional keelsons under engines and boilers; strong and well connected engine seating carefully scarphed forward and aft of engine space; well-built thrust seating and shaft stools; deep floors aft, and the opposite sides of the transverse framing and sides of the ship aft well tied by means of beams and stringer plates, or transverse plate webs; stout shell plates connecting the stern frame to the hull; additional transverse stiffening in the engine and boiler space in the form of deeper framing, web frames, strong beams, and double reverse frames under engines and boilers, as well as efficient pillaring.

3. *Stresses due to Propulsion by Sail.*—These stresses are experienced mostly by sailing vessels, whose lofty masts, heavy yards, and large sail area, when exposed to wind pressure, transmit severe racking stresses to the hull. To prevent damage from this source, the masts should be firmly secured at the heel and deck, and further supported by a good spread of shrouds, stays, etc. To transmit and distribute the stresses at the deck, if no steel or iron deck is laid, the mast should pass through a stout deck plate called a 'mast partner,' which in turn should be brought into intimate association and connection with the neighbouring beams and stringer plates, by means of tie plates carried diagonally across the deck. Owing to the severity of the transverse stresses experienced particularly by sailing vessels, combined with their lack of bulkheads, it follows that the strength of the

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* It will thus be apparent that vibration in many instances depends to a considerable extent upon the speed at which the engines are working. For instance, some vessels are remarkably steady, and no perceptible signs of vibration are experienced when the engines are going full speed. But the same vessels will give indications of slight vibration when the number of revolutions is reduced. Should the speed be still further reduced, and synchronism obviated, the vibration will diminish or disappear altogether.

† Increased depth conduces to minimise vibration, especially in long vessels. The importance, therefore, of carrying the strength well up to the topsides in vessels with continuous erections is apparent.

transverse framing (including beams) and the depth of the beam knees should exceed that required for steamers.

4. *Stresses caused by loading heavy cargoes on deck, and the shipping of heavy seas.*—What is to be hoped for is the complete stoppage of what is now the unusual and dying-out practice of taking out part of the hold pillars when loading timber cargoes in the hold, and afterwards piling up similar cargo on deck. Such a practice is quite sufficient to account for the shearing of beam knee rivets, and other damage. As a matter of fact, under such conditions of loading, a vessel requires all the pillar and beam support that can be given her.

Those who know little of the sea experience of ships, seldom dream what enormous weights of water are sometimes, in the most sudden manner, shipped on deck in boisterous weather. This alone on many an occasion has been sufficient to inflict severe damage upon decks, hold stanchions, beam knees, hatch coamings, bulwarks, etc., not to mention the tremendous force of such seas as they dash against bridge and poop front bulkheads sometimes with very disastrous results, and in some authenticated cases, even causing the foundering of a ship after being struck by a single sea. Such bulkheads should be well strengthened with good coaming plates, and vertical stiffeners kneed to the decks at the top and bottom. Hold pillars, with good heads and heels well connected, or some equivalent structural support, are most essential to support decks under such trying circumstances. Whenever heavy permanent deck weights are carried, good supports or equivalent beams should be provided.

5. *Rudder Stresses.*—The enormous pressure upon the surfaces of rudders, especially in large, heavy, high-speed vessels when turning, throws great twisting stress upon the rudder stock. The necessity for adequate diameter of stock in proportion to the stress experienced is obvious.

Where frame rudders plated on each side are adopted, it is most important that the space between the two plates be well filled with timber so that the whole is one solid mass, with no possibility of panting, for even with this precaution, rudder rivets sometimes work loose.

6. *Stresses from loading aground.*—The trades pursued by some vessels cause them to enter rivers and tidal harbours where, when the tide has fallen, they lie aground. Especially where the bottom is of an uneven stony nature, the weight of cargo which is being loaded or discharged, in addition to the vessel's own weight, tends to crush or bulge in the bottom, and if the bottom of the vessel is only supported at intervals in her length, even bending may occur. The possibility of this latter deformation should be avoided. To strengthen the bottom in order to resist bulging, the bottom plating should be of increased thickness, and be well supported with keelsons, which come down to and are connected with the bottom plating.

7. *Stresses upon vessels which are temporarily only partially Water-borne.*—One of the worst examples of this condition is that in which a vessel runs aground, say, upon a sandbank at high tide, and remains fast

at one end while the other is afloat. The stress endured assumes its worst proportions when the tide has fallen, and the midship portion loses buoyant support in a greater or less degree. This stress is sufficient to so strain many a ship as to break her back. Equally bad is the condition of a vessel stuck at the middle of her length upon a sandbank, so that when the tide has fallen, the ends are left wholly or partially unsupported.

Stresses of such an extreme nature as these the naval architect does not pretend to cover, and he does not hold himself responsible for the results which may accrue.

8. *Launching Stresses.*—In the operation of launching a vessel, and thereby transmitting her weight from terra firma to her own element, she experiences considerable bending moment. This, however, if the vessel be well constructed, is not more than she is able to endure without any danger of damage. Unfortunately, it sometimes happens that vessels stick when they have travelled nearly half way down the launching ways. Under such circumstances, serious damage sometimes results; the great pressure upon the bottom at the end of the ways, and the enormous bending moment which is created by the unsupported overhanging part, is sufficient to crush in the bottom and to severely strain the structure, and produce permanent longitudinal deformation.

Stress and Strain.—In designing the structural arrangement of a vessel, it is necessary that the designer should be thoroughly able to grasp the nature, and to make an estimate of the amount of the severest bending moments likely to occur, and to understand what are the various agencies at work tending to produce deformation in any form whatever.

Forces acting upon any part of a ship and producing deformation, are properly termed 'stresses' with resulting 'strains,' and straining is, therefore, correctly speaking, the measure of the alteration of form. A structure may be extremely strong, but so long as no external force acts upon it, it remains perfectly rigid and inert. Immediately, however, any external forces are experienced, tending to produce either elongation or bending, or other alterations of form, the material in the structure simultaneously arouses itself, as it were, and offers resistance to any such deformation. These internal forces or resistances, equal to the external forces exerted, and tending to restore the structure to its original shape, are 'stresses.' Any deformation is called 'strain,' its amount being proportional to the original stress. Thus, while these terms, 'stress' and 'strain,' are commonly, though inaccurately, used interchangeably by ordinary land folk (ship folk use them correctly when they say 'stress' of weather 'strains' the ship), in the strict mathematical sense there is a distinct difference. Strain is the deformation or change of shape measured in terms of the original dimensions, produced by an external tensile, compressive, shearing or twisting force, though, perhaps, to an imperceptible extent, while stress is what produces the deformation, or is the effort to offer resistance to change of shape. Such stress is measured by the intensity of the force which produces deformation, whether or not it be so great as to cause permanent set, or rupture, or fracture. An old, but nevertheless a very good illustration of strain and stress is that obtained by stretching a piece of india-rubber. The total physical force which is required to produce a certain elongation is, when reduced to rate, say lbs. per square inch, a tensile stress; the elongation, when measured as a ratio of the original dimensions, is the strain; and the internal resistance which is exerted to reduce the elongation and restore the rubber to its original length, is equal to the stress, and may therefore also be called the stress, provided it be measured in the proper way, namely, as a rate, say, lbs. per square inch.

Every 'stress' produces a 'strain,' that is, a deformation, however slight, and (in well-designed structures) quite within the bounds of complete safety. When a bending moment is being experienced which is well within the margin of safety, it must follow that at the same time it is being opposed by a stress of an exactly equal amount. We have, therefore, an absolutely essential condition in order to resist any material permanent and therefore unsafe deformation due to bending or elongating or shearing or twisting forces, namely, that under the severest action of such forces, the material in the structure must be able to develop an internal resistance of at least an equal amount, and well inside of the limit of permanent set. In constructing a ship, it is necessary that such a condition exist, and the material must be so disposed as to secure this.

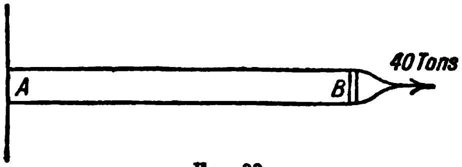


Fig. 33.

Before considering in greater detail the strength of actual ships, which are in effect huge hollow girders made up of combinations of numerous smaller girders, perhaps a little investigation into the strength of simpler sections of material may lead to a clearer conception of the strength of the more complex nature of the ship form.

Let fig. 33 represent a bar of iron or steel of any length by 12 in. deep and 1 in. thick. Suppose it to be firmly secured at one end A, and at the other, B, to be gripped, and a tension of, say, 40 tons, applied in the direction shown by the arrow. Then the 40 tons would be borne by the 12 sq. in. of sectional area, and the tension, or pull, being evenly distributed over the sectional area, would mean a stress of $\frac{40}{12} = 3\frac{1}{3}$ tons per square inch of section. So long as *practically* no extension of the material or permanent set is found to have taken place after the tension is removed, the material has not been stressed beyond its 'elastic limit.'

As shown in Chapter I., elasticity of a body is that property whereby, after it has been subject to a certain pressure, whether of tension or compression, shearing or twisting, at a given temperature, it seeks to regain and retain its original volume and shape at the same temperature. The limit at which the material ceases to resist *permanent* extension or compression is termed the 'limit of elasticity.'

As a matter of fact, tension, even within the elastic limit, produces permanent extension in most materials, though it is found to be so extremely slight that it may, in practice, be ignored altogether.

Under tension, the bar in fig. 33 will stretch (in this case well within the elastic limits) in direct proportion to the force applied, or, in other words, in proportion to the stress. Thus, with a tension of 4 tons, the elongation will be twice that of 2 tons, and so on. However, as soon as a certain point has been reached, viz., the 'elastic limit,' increased tension, and therefore increased stress, produces much more rapid elongation, until eventually the stresses so increase that fracture is produced. The stress necessary to produce this fracture determines the '*ultimate strength*' of the bar. In determining the scantling of a steel or iron bar, or a girder, or a ship which is subject to repeatedly applied tension and compression throughout its length, or locally in its structure, it is absolutely essential, if the strength is to be maintained, that the material be preserved from stresses approaching the elastic limit, or, in other words, an ample margin of safety is necessary. The ultimate tensile strength of good mild steel plates, such as are used for the construction of ships built to Lloyd's requirements, is not less than 28 nor more than 32 tons per square inch of section, with or across the grain, and for iron an ultimate tensile strength of at least 20 tons per square inch with, and 18 tons across the grain, is demanded.

Ductility and the Elastic Limit.—Since brittleness is a most objectionable feature in ship steel or iron, a standard for ductility is imposed. Steel must stand an elongation of at least 16 per cent. on a length of 8 in. before fracture. Of course, such extension is only demanded in testing. It is never supposed that any such extension will take place in the actual ship. Indeed, as is evident, such stress as is experienced in producing these elongations is far beyond the elastic limit, and, as previously pointed out, the material should not be subject to a stress which is likely even to approach that producing permanent elongation. The elastic limit of ship steel, whose ultimate tensile strength has been given, would be from about 17 to 20 tons, and of iron, 10 to 13 tons. This at once shows the unmistakable superiority of steel over iron, and it explains why steel ships are so much lighter than iron ones, the reason being, as has been shown, that a square inch sectional area of good mild steel will develop a strength equal to at least 1½ square inches of good iron.

However, it must not be reasoned from this that steel ships are therefore 33 per cent. lighter than iron ones. There are more things than merely tensile strength and elastic limit to be considered in determining the scantlings of plates and bars.

Thickness gives stiffness, and were steel plates to be unreasonably reduced in thickness, in some cases buckling of a very serious nature would inevitably ensue. Moreover, this reduction is practically only to be found in the plates and angles, and does not materially affect the equipment, ship fittings, stem bar and stern frame, keel bar, etc.

But supposing, as is quite reasonable, that a saving of 100 tons weight is effected in a 3000 ton ship, owing to the adoption of steel instead of iron for her hull construction, this to the shipowner is an important consideration, for his ship will now carry 100 tons more deadweight than if she had been made of iron, and deadweight means freight. As a result, steel has almost entirely superseded iron for ship construction, excepting in certain localities in the vessel. These localities we shall observe at a later stage.

The working stress of steel or iron should not exceed 50 or 60 per cent. of the elastic limit. Hence, taking the elastic limit of ship steel at 18 tons, the maximum working stress should not exceed 9 or 10 tons, with the severest stresses the material may under exceptional circumstances have to sustain. The ordinary stress will of course be well within this extreme limit.

Again, let fig. 34 represent a bar of iron or steel 12 in. deep by 1 in. thick. It is supported at the points A and B at the ends. The bar is weighted with a load uniformly distributed over its length. The tendency now is for deformation to take place, and the bar to bend as shown. So long as this condition exists, and the stress does not exceed the elastic limit, the bar bends into a curve whose shape and amount of deflection can be ascertained by methods laid down in books on practical mechanics. Assume here that X is the centre of a circle of which $A_1 B_1$ is the arc. It is evident that before the bar could have assumed this shape, considerable extension or stretching must have taken place on the side $A_1 B_1$, and an equal amount of compression on the side P Y. It is also clear, if the compression and extension are identical in amount, that midway between these two surfaces of the bar there must be a layer where neither extension nor compression has taken place. This layer is termed the '*neutral surface,*' and passes through the centre of gravity of the section of the bar, which in this case is at half its depth. A transverse line passing through the centre of gravity of the bar is called the *neutral axis* (see fig. 34). When the bar was straight, G H and J K were two transverse sections perpendicular to the sides P Y and A B; now, however, in the bent bar they have become inclined as in $G_1 H_1$ and $J_1 K_1$ intersecting the parallel lines E F and C D at the points M_1 and N_1 in the neutral surface (note M N is equal to $M_1 N_1$). So that F D has stretched to $H_1 K_1$ and E C has been compressed to $G_1 J_1$.

The elongation and compression for any layer in the bar varies directly in proportion to the distance of the layer from the neutral axis. Within the elastic limits we have previously pointed out that the elongation varies directly in proportion to the stress. Similarly, the compression varies in direct proportion to the stress. Hence it follows that as the upper and lower layers in the bar are further from the neutral axis than any intermediate one, the stresses must be greater towards the upper and lower edges, and this is exactly the case. The stresses vary in direct proportion to their distance from the neutral axis.

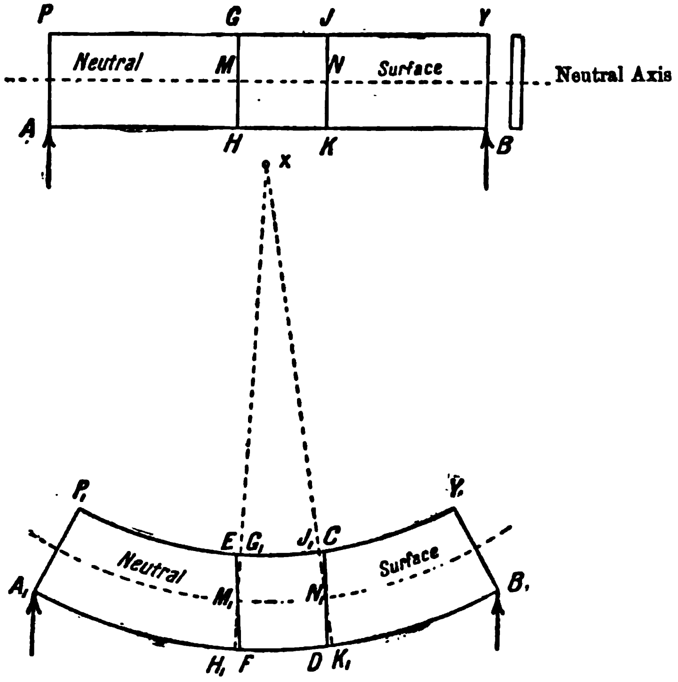


Fig. 34.—Illustrating Elongation and Compression in a bent bar; also Neutral Surface.

Moment of Inertia.—Let fig. 35 represent an enlarged side view of the bent bar shown in fig. 34 (12 in. deep by 1 in. wide), and let A, B, C, D, E, F, G be infinitesimally small units of area in the cross section of the bar X, Y. The bar is still supported at the ends as before, and the weight distributed over the length, producing the tendency to bend as shown. The resistances offered by every unit of area in the cross section above the neutral axis to compression, and below the neutral axis to elongation are the stresses. Supposing the distance between the units of area to be equal to one another, and A be on the neutral axis, the stress on A will be nil; at B it will be, say, x; at C, $2x$; at D, $3x$; at E, $4x$; at F, $5x$; at G, $6x$. Moreover, these resistances are exerted in lines of action parallel to the upper and lower surfaces of the bar at their respective leverages from the neutral axis as shown by the arrowed lines. Thus, while the stresses increase in proportion to the distance of the unit of area from the neutral axis, the moments of these stresses, or moments of resistance, increase in proportion to each stress multiplied by its respective leverage from the neutral axis.

The sum of all these moments of resistance gives a total moment of resistance equal to the total bending moment.

It will be observed that the depth of the bar in fig. 35 is divided by the arrowed lines into twelve strips, each 1 in. in depth.

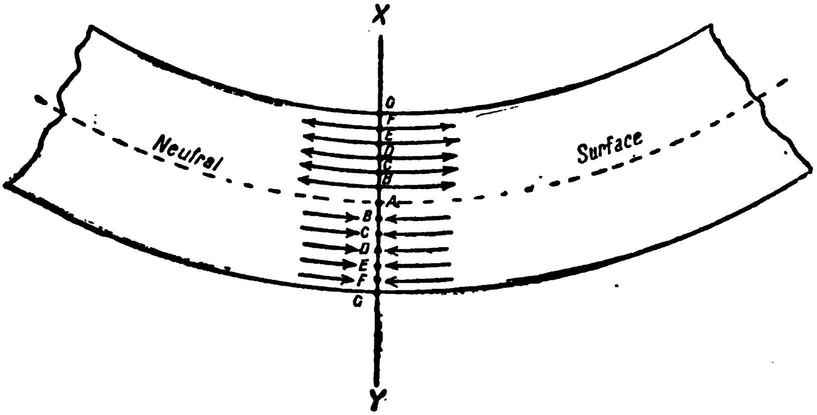


FIG. 35.—The arrowed lines in the upper half of the bar represent the resistance of the material to compression, or compressive stresses. The arrowed lines in the lower half represent the resistance to elongation, or tensile stresses.

The calculation should be :—

A

Let R = stress at distant edge of 1st strip.

Then, stress = an average of $\frac{1}{2}$ R lbs. per square inch.

(average $\frac{0 + R}{2}$) on strip of area A B, ... I.

Then on strip B C, average stress is $\frac{R + 2R}{2} = \frac{3}{2}R$ . . II.

" " " C D " " $\frac{2R + 3R}{2} = \frac{5}{2}R$ . . III.

" " " D E " " $\frac{3R + 4R}{2} = \frac{7}{2}R$ . . IV.

" " " E F " " $\frac{4R + 5R}{2} = \frac{9}{2}R$ . . V.

" " " F G " " $\frac{5R + 6R}{2} = \frac{11}{2}R$ . . VI.

Leverage in each case respectively is approximately :—

		inches.
B	I.	$\frac{1}{2}$
	II.	$\frac{3}{2}$
	III.	$\frac{5}{2}$
	IV.	$\frac{7}{2}$
	V.	$\frac{9}{2}$
	VI.	$\frac{11}{2}$

Moments (A × B) are :—

$$
\begin{array}{l}
\frac{1}{2} \times \frac{1}{2}\,R = \frac{1}{4}\,R \text{ inch lbs.} \\
\frac{3}{2} \times \frac{3}{2}\,R = \frac{9}{4}\,R \quad ,, \quad ,, \\
\frac{5}{2} \times \frac{5}{2}\,R = \frac{25}{4}\,R \quad ,, \quad ,, \\
\frac{7}{2} \times \frac{7}{2}\,R = \frac{49}{4}\,R \quad ,, \quad ,, \\
\frac{9}{2} \times \frac{9}{2}\,R = \frac{81}{4}\,R \quad ,, \quad ,, \\
\frac{11}{2} \times \frac{11}{2}\,R = \frac{121}{4}\,R \quad ,, \quad ,, \\
\hline
\text{Sum} \quad \frac{286}{4}\,R \text{ inch lbs.}
\end{array}
$$

For both sides of neutral axis double $= \frac{286}{2}\,R = 143\,R$ inch lbs.

[Worked out by accurate integrational formula $\left(f\frac{bd^2}{6}\right)$ gives exactly 144 R.]

Now, if we multiply every little area patch in the cross sections we are dealing with by the square of its distance from the neutral axis, and add them up, we get the same number as before, viz. (accurately) 144. This number has a special and well-known name. It is called the '*Moment of Inertia* of the section,' about the centre of gravity of the section.

Practical men may justifiably assume that the quantity called 'Moment of Inertia,' which, to begin with, is a purely mathematical quantity, has a physical meaning and a practical use in practical shipbuilding and other constructive work.

We have seen that the moment of resistance to bending in a bar or girder—whether it be plain, thus I, or complicated, as shown by the midship section of a ship, which shows the ship girder in section—equals the sum of the moments of the stresses about the neutral axis of each sectional area of the girder.

In working through the foregoing illustration, we commenced by assuming a certain stress on a unit of area at a unit of distance from the neutral axis. But in actual practice, when dealing with a loaded bar, as in fig. 34, it is the maximum stress (*i.e.* at the outermost layers) that has to be ascertained in order to see whether the material is being strained at these layers beyond the elastic limits, when, of course, permanent elongation, or 'set,' or perhaps even rupture would occur. It is therefore evident that the calculation will be carried out in office work by dealing with the value of R at the outermost layers.

However, the stress at 'unit' distance from the neutral axis enables us to arrive at a useful quantity by which the desired result can be obtained.

This quantity, the *moment of inertia* of the whole cross section of the bar, and represented by 144 in this example, equals the sum of the products of *every* unit of area in the cross section multiplied by the square of the distance of each unit from the neutral axis.

As we have seen, the moment of resistance for the whole cross section is the sum of the moments of all the stresses in the cross section of the bar. So that the moment of resistance at the section in question equals the moment of inertia multiplied by the stress at a unit of distance from the neutral axis.

Hence the total moment of resistance divided by the moment of inertia equals the stress per unit of area at a unit of distance from the neutral axis. But so long as the material in the bar is not subjected to stresses beyond the elastic limit, the moment of resistance is equal to the bending moment.

Therefore the bending moment divided by the moment of inertia equals the stress per unit of area at a unit of distance from the neutral axis.

Let I = Moment of inertia of a cross section,
and M = Bending moment of same cross section;
then $\frac{M}{I}$ = Stress per unit of area at unit of distance from neutral axis,

in the same cross section.

But, as we have seen, the stresses increase from the neutral axis towards the upper and lower surfaces in proportion to the distance.

Let P = distance of upper surface from neutral axis,
„ K = „ lower „ „
Then $\frac{M \times P}{I}$ = maximum stress per unit of area upon upper surface of bar;
and $\frac{M \times K}{I}$ = „ „ „ lower „

In practice, *the unit of area is the square inch*, and the stress obtained is therefore stress per square inch.

Of course in the bar of the section shown in figs. 34 and 35, the neutral axis passes through the centre of gravity of the bar, which is at half the depth, because it was assumed that the bar would resist extension and compression equally, and therefore P = K. However, in a bar of T section, or indeed any other section, P and K would not necessarily be equal.

The value and reasons for making girders and bars of the following sections will now be obvious.

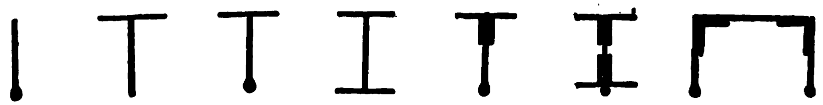


FIG. 36.

As the stresses increase in magnitude as the distance increases from the neutral axis, by adding flanges, or bulbs or plates, to the upper and lower extremities, the moments of inertia of the sections are greatly augmented, and the stresses are more readily met.*

Before proceeding to show how the bending moment is ascertained, it is hoped, by means of another simple graphic illustration, to make this subject of moment of inertia still more comprehensive, and to dispel a mistaken idea which has grown among many young students that it is almost too difficult and mysterious and intricate to understand.

Here is a section of a bar of iron 10 in. deep, and 2 in. thick, $x\ y =$ the neutral axis. The section of the bar is divided into units of area of 1 square inch, the unit of area adopted in practice. The total amount of inertia of the bar about the neutral axis is found by multiplying each unit of area by the square of its distance from the neutral axis.

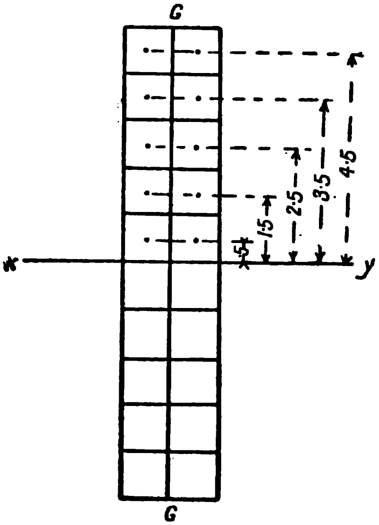


Fig. 87.—Illustrating Moment of Inertia.

The moment of inertia of the upper half of the section of the bar =

$$\begin{aligned} 2 \times \cdot 5^2 &= 0\cdot 5 \\ 2 \times 1\cdot 5^2 &= 4\cdot 5 \\ 2 \times 2\cdot 5^2 &= 12\cdot 5 \\ 2 \times 3\cdot 5^2 &= 24\cdot 5 \\ 2 \times 4\cdot 5^2 &= 40\cdot 5 \\ \hline &\ 82\cdot 5 \end{aligned}$$

And for the lower half of the bar section it will be 82·5 also, making a total of 165.

Supposing the bending moment to be 100 inch-tons, the stress on 1 square inch at 1 in. from the neutral axis would be $\frac{100}{165}$, and at the layer on the upper and lower surfaces of the bar (G) would be $\frac{100 \times 5}{165} = \frac{500}{165}$ = about 3 tons per square inch, this being the maximum stress.

---

* Tensile and compressive stresses are always greatest in that part of the material which is farthest from the neutral axis.

The method just adopted to calculate the moment of inertia of the section of this bar is exactly similar to that adopted in ship calculations, but it must not be supposed that it is absolutely correct, though it is sufficiently accurate for all practical purposes. To begin with, our units of area are not infinitesimally small (we have taken 1 square inch). Hence there is a slight error in the moment of inertia. The correct moment of inertia of this bar (true for rectangular sections only) would have been

$$\frac{\text{thickness of bar} \times \text{depth}^3}{\text{constant } 12} = \frac{2 \times 10^3}{12} = 166 \cdot \dot{6}, \text{ a difference of } 1 \cdot \dot{6}.$$

We can get as near this as we like by making the strips narrower and narrower.

Reverting now to diagram 35 (bar supported at ends) the actual moment of inertia of its section (12 in. × 1 in.) will be $\frac{1 \times 12^3}{12} = 144$, as previously shown.

We also know that the centre of gravity of such a section would be at half the depth, and that through the centre of gravity passes the neutral axis of the bar. The stress, therefore, upon either of the extreme surfaces on the top or bottom of this rectangular bar will be :—

$\frac{\text{Bending moment} \times 6}{144}$ = Stress per square inch at most severely strained part (outermost edge).

Bending Moment of Girder.—Having, it is hoped, made reasonably clear the value of the moment of inertia of a girder section, and explained the principles involved in arriving at a computation of the same, our next step will be to show how the actual bending moment is arrived at, though in a simple form this has already been treated (see page 67).

Curve of Loads.—Let A B, fig. 38, be a bar somewhat similar to that dealt with in fig. 28, and loaded with a continuous load as indicated by the hatched lines. Let the bar be, say, 20 ft. long.

At 2 ft. intervals on A B, set up ordinates, calculate the weight of the bar per foot with its load, and set up the results to scale, each upon its respective ordinate. Through the points so obtained draw the curve A C B. The total area of this curve represents to scale the total weight resting upon the supports at A and B, and the centre of the area (G) enclosed by A B and the curve A C B, represents the fore and aft position on the line A B of the centre of gravity of the bar and its loading. The curve A C B is termed *a curve of loads.*

Now it is evident that the upward pressures of the supports upon the ends of the beam must be equal to the downward pressure of the total weight of the bar and its load; but as the centre of gravity of the load is not, in this example, in the middle of the length of the bar, the pressure of the supports at the ends will be unequal.

To find the supporting pressures at the ends of the bar.—Let L = total load, and P and Y the supporting pressures.

Then L = P + Y.

$$(P \times AB) + (Y \times AB) = L \times AB$$

and $$\frac{P \times AB}{L} = k$$

" $$\frac{Y \times AB}{L} = d$$

Thus, so far, we have obtained the total load, and the pressure at each end of A B supporting the same load.

Curve of Shearing Stresses.—By a process of graphic integration, we now proceed to ascertain the bending moment. This is first done by constructing a *curve of shearing stresses.*

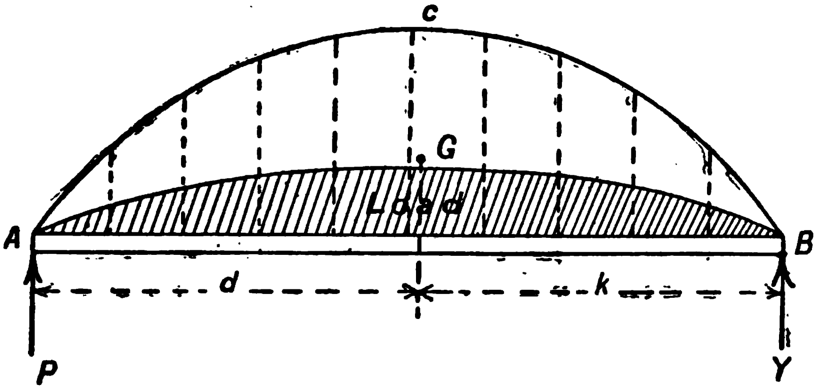


FIG. 38.—Curve of Weight A C B for a loaded bar.

Let A B, fig. 39, represent the bar, with the curve of loads A C B upon it, with ordinates at 2 ft. intervals. Make A M (set off above A B) equal to the pressure P, and B N equal to the pressure Y (set off below A B). The shearing stress at any point in the length A B is the difference between the supporting pressure on that side of the centre of gravity, and the weight represented by the area of the curve of loads from the end of the bar up to that point.

Thus the shearing stress at

d = P − (weight represented by area A $X d$.)
and at e it equals P − (" " " " A $X'e$.)
" f " P − (" " " " A $X''f$.)

These differences are set off from A B on their respective vertical lines to the same scale as adopted for A M and B N. Naturally, as we travel from A towards B, the difference between the pressure P and the weight represented by the successive areas A *X* *d*, A *X'* *e*, etc., grows less and less, until, at a certain point O, the pressure and weight are exactly equal, and if we proceed beyond this point towards B, the weight preponderates, and the difference, which is now negative, is set off below A B. Similar results would have been obtained had we commenced from B and deducted from B N the successive weights, represented by the areas of the curve from B (except that in the drafting, the curve would have been above at the B end and below at the A end).

Let M O N be the curve of shearing stresses so obtained. The effect of these opposite, or negative and positive, shearing stresses, is to produce the tendency to rack or distort the beam by bending, and the point O is known as the point of reverse racking, or the point at which the racking action is reversed. In addition, the curve of shearing stresses shows the tendency to shear (*i.e.* cut through) at any cross section.

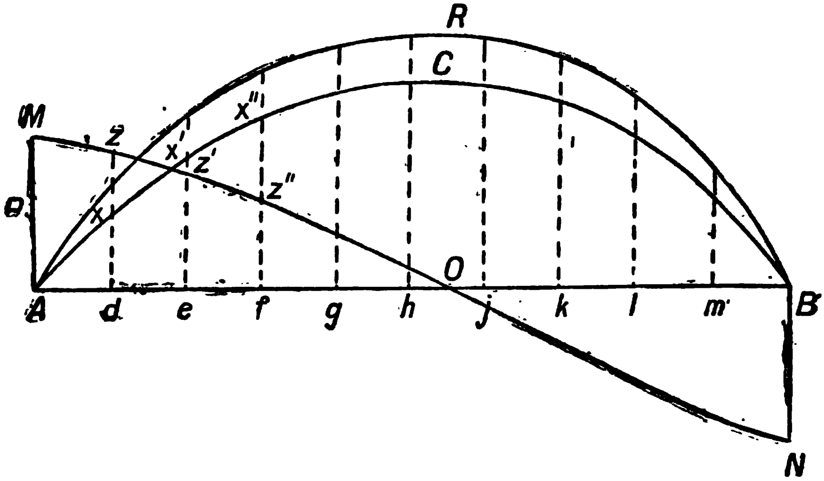


FIG. 39.—Curve of Shearing Stresses M O N, Curve of Bending Moments A R B (A C B Curve of Weights).

From this curve of shearing stresses we are able to ascertain the bending moment at any point.

As previously shown, the shearing stress at any point in the length of a beam or bar is simply the difference between the pressure (reaction) at one end, and the weight upon the bar up to that point, from the same end; or, in other words, it is the resultant of the forces of the downward weight upon the bar and the upward pressures at the ends reckoned at any cross section in the length of the bar.

Curve of Bending Moments.—In addition to the tendency to shear between the points of support, there is a *tendency* to bend also. Now the bending moment for any *one* load at any section in the length of a bar supported at the ends is equal to the pressure (reaction) at either end, multiplied by the distance of the section from that end of the bar; and, in general, for any loading, it is the algebraic sum of all the shearing stresses on the bar between the cross section and the end of the bar.

The area, therefore, of A M O represents the bending moment at O, and, similarly, the area O B N represents the bending moment at O, since A M O = O B N. Thus at the point O where the racking reverses, the maximum bending moment is experienced. In order to graphically represent the bending moment at any section in the length A B, the area of the curve of shearing stresses would have to be calculated at intervals from either end of the bar, and set up to scale at their respective positions throughout the length of A B. For example, the area of A M *Z d* would be set up at *d*, and A M *Z′ e* at *e*, and so on up to O, where the bending moment attains its maximum. The shearing stresses now become negative, and are subtracted from A M O instead of added. Through the points so obtained the curve A R B is drawn. By means of this curve, the bending moment may be found at any cross section in the length of the bar by measuring the perpendicular distance from A B to the curve.

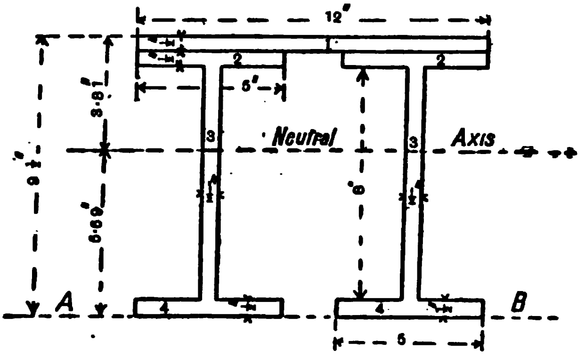


Fig. 40.—Compound Girder.

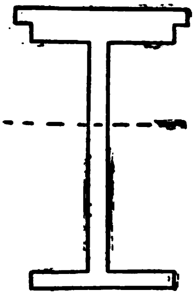


Fig. 41.—Equivalent Girder.

Stress per Square Inch.—It has now been shown how each part in the equation for stress in the bar example is obtained. Thus (for units using inches and either lbs. or tons as most convenient):—

$$\frac{\text{Bending moment}}{\text{Moment of Inertia}} = \begin{array}{l}\text{Stress per square inch of section at 1 in. from the}\\ \text{neutral axis.}\end{array}$$

$$\frac{\text{Bending moment} \times \left\{\begin{array}{c}\text{distance of upper or lower}\\ \text{surface of bar from the}\\ \text{neutral axis.}\end{array}\right\}}{\text{Moment of Inertia.}} = \text{Maximum stress per square inch.}$$

The Equivalent Girder.—So far we have only been dealing with the very simplest form of bar, viz., of rectangular section. But supposing it to have been of a more complicated form of section similar to that shown in fig. 40, a little more trouble would have been entailed in obtaining the moment of inertia.

By closing up the material in any compound girder section into one compact girder, we have a consolidated girder of equivalent sectional area and with similar vertical distribution of such area. This is usually called an *equivalent girder.* (See fig. 41 which shows fig. 40 contracted horizontally).

An equivalent girder is rarely constructed before making the calculation for the moment of inertia of a section of a ship. But while the diagram affords a graphic way of presenting the material in the sectional area, it serves little other purpose, and, as a result, the equivalent girder is seldom constructed in mercantile shipyard practice, though, in making the calculation, precisely the same process of combining the material is carried out. Fig. 42 illustrates a section of a vessel with its corresponding equivalent girder.

Computation of Moment of Inertia of Compound Girder.—Perhaps it may afford a useful example to compute the moment of inertia of the section of such a girder as shown in fig. 40, relatively to its neutral axis, as the calculation will be identical in every way with that for the moment of inertia of the section in the more complicated ship-girder. The distance of the neutral axis (which passes through the position of the centre of gravity of the area of the section) from the base line A B is found by multiplying the area of each part composing the section by its distance from A B and dividing the sum of the moments by the sum of the areas. Or it could be found by assuming a neutral axis and dividing the difference of the moments above and below the assumed neutral axis by the total area of the section. The result is the amount of correction necessary for the

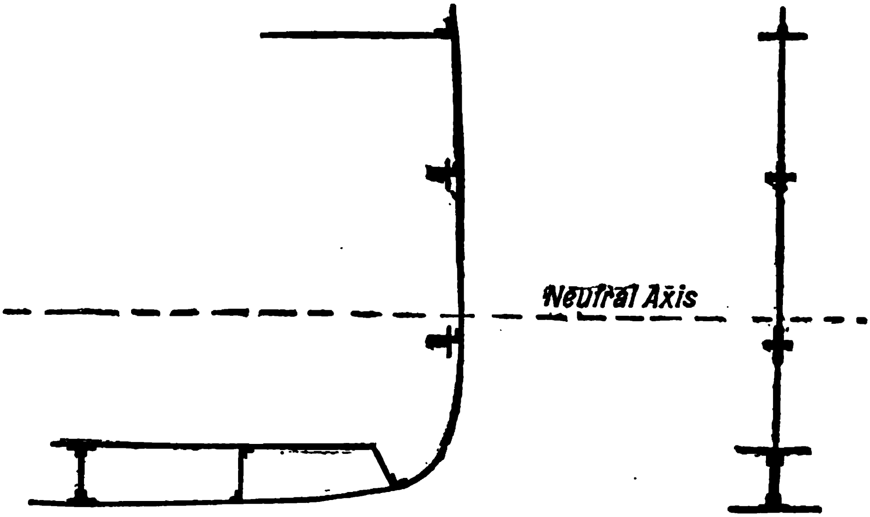


FIG. 42.—Midship Section of a Vessel showing the structural material embraced in the Equivalent Girder, and dealt with in the Calculation for Moment of Inertia (see fig. 12.)

actual position of the neutral axis, and the side upon which the moments preponderate indicates the direction in which the correction has to be made.

Reference to fig. 37 will enable us to more easily follow the steps in the process of calculation. In that example it was shown that the moment of inertia about the neutral axis of any unit of area was obtained by multiplying the area by the square of its distance from the neutral axis,—one square inch being taken as the unit of area,—and that the sum of the products of all the units of area in the section multiplied by the squares of their respective distances gave total moment of inertia.

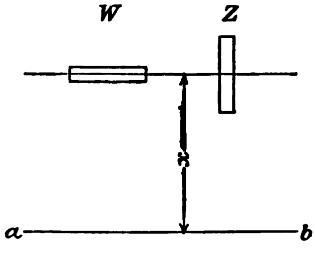
Exactly the same process is followed in dealing with the girder section, fig. 40. In all sections of material disposed horizontally (*i.e.*, parallel to neutral axis) see Nos. 1, 2, and 4 flanges of girder, and of small depth or thickness, the areas in inches, which represent sums of units of areas, multiplied by the squares of their distances from the neutral axis, will give their respective moments of inertia about the neutral axis. But on coming to vertical webs (No. 3) or areas disposed vertically, while the area is again multiplied by the square of the distance of its centre from the neutral axis, this only treats of the units of area as though they were all ranged exactly parallel to the neutral axis of the girder, which is not the case. We have already considered the value of the moment of inertia of a vertical web about its own neutral axis, which, in a case like this under consideration, would produce a total moment of inertia about the girder neutral axis in excess of what would have been obtained had the same material been disposed horizontally.*

Proceeding with the calculation :—

1st. To find the neutral axis of the whole girder. It is obvious that the

---

* In the accompanying illustration W and Z are similar in size and of equal area, the difference being that one is placed horizontally and the other vertically in relation to the line *a b*, while the centre of gravity of each is at the same distance from *a b*. The moment of inertia of Z about the line *a b* is equal to the moment of inertia of W, plus its own moment of inertia about its own neutral axis, which latter in actual calculations may be expressed as $\frac{1}{12}$th of depth cubed × breadth; or, more usually, as $\frac{1}{12}$th of area × depth squared, which is exactly the same.



It is theoretically true that horizontal flanges have a moment of inertia about their own neutral axis also, but in practice it is so insignificant as to be entirely ignored. Decks, and inner and outer bottoms, are similar horizontal flanges in actual ship girders.

Assuming the dimensions of W and Z to be 10″ × 1″ and the distance x to be 20″:—

Then the moment of inertia of

$$\text{W about } a\,b = (10 \times 1 \times 20^2) + \left(\frac{10 \times 1^2}{12}\right) = 4000{\cdot}8,$$

and

$$\text{for Z about } a\,b = (10 \times 1 \times 20^2) + \left(\frac{10 \times 10^2}{12}\right) = 4083{\cdot}3.$$

centre of gravity of each of the I parts of the girder is at half the depth, that is, 4½ in. above A B.

The centre of gravity of the top plate (which is ½ in. thick) will therefore be at 9¼ in. above A B.

The common centre of gravity, through which the neutral axis passes, will be obtained as follows:—

The two I parts of the girder contain together 18 square inches in sectional area, and the top plate 6 square inches.

	Sectional Area.	Distance of Centre of Areas of Girder above A B. Leverage.	Moment.
	sq. ins.	ins.	
2. I Parts of Girders,	18	4·50	81·0
Top Plate, . . .	6	9·25	55·5
	24		136·5

$$\frac{136\cdot 5}{24} = 5\cdot 69 \text{ inches above A B.}$$

The neutral axis of the whole girder is 5·69 inches above the line A B.

2nd. To find the moment of inertia of the section of the girder about the neutral axis.

The following is the usual form of the calculation:—

Particular Items in Girder.	Sectional Area = A	Distance of Centre of Gravity from Neutral Axis = h	Products. $A \times h^2$	Depths of Vertical Webs = d	d^2	$\frac{1}{12} \times A \times d^2$
	sq. inches.	inches.		inches.		
Item 1	6	3·56	76·02	·5	·25	...
„ 2	5	3·06	46·80	·5	·25	...
„ 3	8	1·19	11·28	8·0	64·00	42·66
„ 4	5	5·44	147·95	·5	·25	...
			282·05			42·66
			42·66			
			324·71 Moment of Inertia.			

Stress per square inch upon upper and lower surfaces of foregoing girder.

The total depth of the girder = 9·5 in.
From neutral axis to top of girder = 3·81 „
„ „ „ bottom „ = 5·69 „

Suppose the girder to be subject to a maximum bending moment of 14 foot-tons = 168 inch-tons.

The tensile stress per square inch upon the upper surface of the girder will be

$$\frac{168 \times 3\cdot 81}{324\cdot 71} = 1\cdot 97 \text{ tons,}$$

and the compressive stress per square inch upon the bottom surface of the girder will be

$$\frac{168 \times 5\cdot69}{324\cdot71} = 2\cdot94 \text{ tons.}$$

Having briefly shown how to obtain the moment of inertia, and the bending moment of a loaded bar or girder of plain section, it is found, on turning to an actual ship, that though the labour of calculation is considerably increased, the principles worked upon, and the steps in the calculation, are practically identical in arriving at the results.

Bending Moment of an actual Ship.

Curve of Weights.—The first operation is to determine the distribution of the weights in the vessel. This curve may show great variation, especially in a cargo-carrying vessel, according as to whether the vessel is ballasted, light, or in a loaded condition. For the sake of example, let us suppose that fig. 43 represents the profile of the vessel for which the

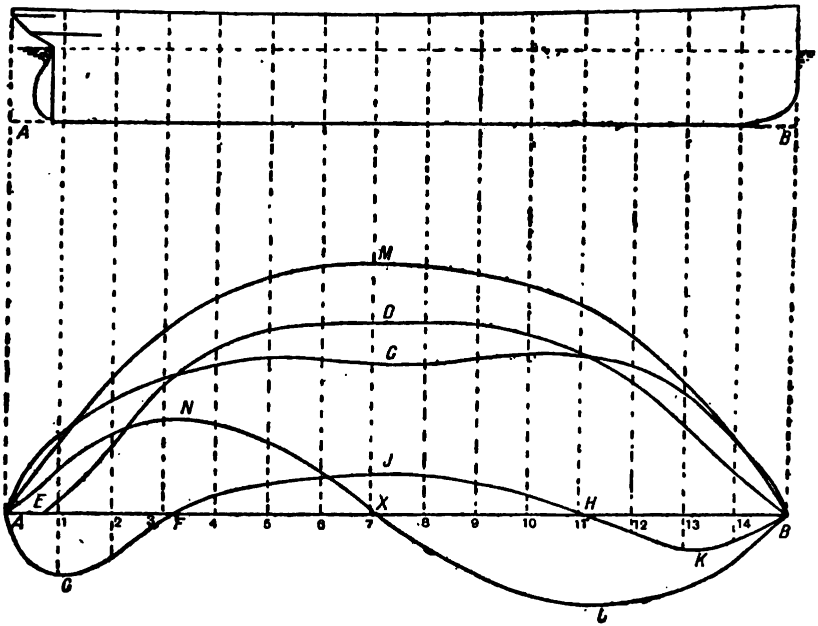


Fig. 43.

ACB = Curve of Weights.
EDB = „ Buoyancy.
AGJKB = „ Loads.
ANLB = „ Shearing Forces.
AMB = „ Bending Moments.

calculation of bending moment has to be made. As in the case of the bar, we lay down a base line A B equal to the length of the ship. Assuming that we have a lines plan which enables us to obtain the girth and section of the vessel at any point in the length of the hull, and assuming also that we have a constructive plan showing in profile and section the scantlings, arrangement, and disposition of all the material and distribution of all permanent weights, we are fully equipped with the information necessary, in order to proceed with the determination of the curve of weights for the light condition.

Divide the length of the vessel into a number of equal intervals, say 15, and, at each division, calculate the weight of the material in the vessel for one foot of the length. This will mean 1 ft. of all material which runs continuously fore and aft; but for transverse framing, beams and pillars, which are probably spaced at intervals of more than 1 ft., the proportion of the weight which belongs to 1 ft. of length will be taken. Exceptional weights, such as the stern frame, stem bar, etc., should be added later, only the longitudinal and transverse framework and plating being calculated at this stage. These 'weights per foot' are then set off to scale from the base line A B on their respective ordinates.

Assuming the vessel to be in a light condition, propelled simply by sail, a few additions will still have to be made to the curve of weights. Masts and rigging, winches, windlass, anchors and cables, and whatever stores and other equipment and spare gear there may be on board, should all be included in the vessel's weight, and appear in their proper localities in the curve. Had the vessel possessed a poop, bridge, or forecastle, these would also have added to the local weight. If she had been a steamer, there would have been the further additional local weight of engines, boilers, bunkers, shafting, propeller, funnel, etc.

Suppose, again, the vessel to be in a ballast condition, with water ballast in a double bottom, extending fore and aft along the bottom, with, in addition, as is common, peak tanks at the ends, and perhaps a large deep tank somewhere in the region of amidships. The weight per foot of length of all such ballast should be calculated, and added to the curve of weights.

In the loaded condition, however, a vast increase takes place in the area of the curve of weights. Fully loaded with a miscellaneous cargo, which probably changes on each succeeding voyage, it is obvious that no accurate curve of weights could be obtained for the loaded condition on any particular voyage.

The practice is therefore to assume that the vessel's holds are filled with a homogeneous cargo which exactly puts her down to the load line. Knowing the total volume of the holds, and the deadweight of the vessel $\frac{\text{cubic feet hold capacity}}{\text{deadweight}} = $ cubic feet per ton stowage. Therefore, the number of cubic feet of hold space per foot of length, at each of the respective stations in the length, divided by the number of cubic feet per ton of stowage, gives the tons addition to be made to the curve of weights in the light condition.

In short, the curve of weights accurately represents the weight per foot at any point in the length, and its total area represents the total weight of the vessel *for a specified condition.* This will generally be for the fully loaded condition, when the greatest bending moments may be experienced in wave water, or even for a ballast condition when the concentration of large volumes of water in certain localities in a vessel's length may also produce excessive bending moments at sea. With the increasing adoption of large deep tanks, and even hold spaces for water ballast, it seems that shipbuilders will be required to give very special attention to the proper strengthening of ships, so as to effectively resist strain, which the concentration of great weight is liable to produce.

Assuming that the process of calculating the weights of a sailing vessel for the loaded condition has been completed, let A C B (fig. 43) represent the curve of weights.

In reality, the method described for calculating the weights of a vessel throughout her length, would not produce a curve at all, but rather an uneven, and, in some places, a very jagged line bounding the area representing the total weight. Sometimes the irregular boundary of the area is dealt with just as it is produced by the computation of the actual weight; but it is more commonly the practice to run a mean curve embracing, as far as possible, all the features of the irregularly bounded area first obtained. This new curve, if correctly drawn, should accurately represent the total weight of the vessel. The calculation just described, as is evident, entails a considerable amount of labour, though of a very simple character.

Curve of Buoyancy.—Having ascertained the amount and distribution of the weight as shown by the curve of weights, the next step is to determine the distribution of the support given by the water in the form of a *curve of buoyancy.*

Whatever be the condition of loading, we are aware that the total support given by the water (buoyancy) is exactly equal to the total weight of the ship and all in it. This condition is fulfilled whenever a vessel floats in equilibrium. It is needless to say that (in ascertaining any particular result) the calculation is based upon a certain condition of loading, which means a fixed draught, the mean of which, in either smooth or wave water, remains practically constant.

The volume of displacement per foot of length, at each of the stations upon A B, fig. 43, is calculated; this volume divided by 35 (salt water), gives tons of buoyancy per foot. Set these off upon their respective ordinates to the same scale as used for the curve of weights. A curve through the points so obtained will give the curve of buoyancy. By means of this curve, the buoyancy per foot can be ascertained at any point in the length of the vessel, and its whole area represents the total buoyancy of the ship.

For either a light, ballasted, or loaded condition, the curve of buoyancy would be worked out in identically the same manner,—the volume in each case being taken up to the water-line, at whatever trim for the particular condition. Let the curve E D B, fig. 43, represent the curve of buoyancy for the fully loaded condition. If the calculation has been correctly worked, the total area of the 'curve of weights' should exactly equal the total area of the 'curve of buoyancy' for the same condition of loading.

Curve of Loads.—Curves A C B and E D B show exactly where, and to what extent, the weight preponderates locally over the buoyancy, and the buoyancy over the weight. By carefully measuring the *difference* upon the ordinates between the two curves, and setting off the excess of buoyancy above the line A B and the excess of weight below A B, we have what is called the *curve of loads.* The points F and H indicate where the buoyancy and weight are exactly equal to each other and are known as water-borne sections, and in the next stages of the calculation, these being the only points in the length where the buoyancy exactly sustains the weight, they are considered as the points of support.

As a necessary condition for any vessel to float in equilibrium is that the centre of buoyancy and the centre of gravity be in the same vertical line, it follows that the centre of gravity of the area enclosed by the curve of weights A C B and the curve of buoyancy E D B, and also of the sum of the three parts of the area enclosed by the curve of loads A G F, F J H, H, K, B, will be in the same vertical line.

Curve of Shearing Forces.—Following the same graphic method adopted in dealing with the plain bar, we proceed to obtain the *curve of shearing forces.*

Calculate the area of the 'curve of loads,' commencing from A to each of the succeeding ordinates. Set these areas off above A B. The ordinates in the curve will continue to grow up to the point F. But as the curve of loads at this point crosses A B, the areas of the curve of loads above A B will now be deducted from the foregoing area, until, at X, the shearing curve crosses A B, when the ordinates now begin to extend below A B up to the point H in the curve of loads, when deduction of the succeeding areas of the curve of loads produces the curve of shearing forces as shown. The shearing force at any point in the length of a vessel may be expressed as the algebraic sum of all the stresses caused by the excess of weight and buoyancy from either end.

Curve of Bending Moments.—Finally, the bending moment at any section in the length of the vessel is represented by the area of the curve of shearing forces from A or B. From A, the ordinates for the curve of bending moments will continue to grow in height up to the point x in the curve of shearing forces, where it attains its maximum. Beyond x from A, the areas of the curve of shearing forces should be deducted from the area obtained up to x. By calculating the bending moment at intervals along A B, a curve showing the whole range of the bending moments is obtained, A M B, fig. 43. The length of any ordinate from A B to the curve A M B gives the bending moment at that point in the length of the vessel for the fully loaded condition, and floating in *smooth water* at F and H, where the curve of shearing forces attains its greatest height, are indicated the points of maximum shearing force. The bending moment at any point in the length of a vessel may be expressed as the algebraic sum of all the shearing stresses from either end.

So far, we have simply considered a sailing vessel fully loaded and floating in still water at her maximum draught. But the curve of bending moments, for such a condition, in no way represents the extremes of the bending moments experienced by the ship; for, while in wave water the distribution and the amount of the weight itself remain constant, great alterations take place in the distribution of the buoyancy, causing great augmentation in the excess of weight over buoyancy and buoyancy over weight in certain localities in the length, as the waves change in form and position, thereby producing vastly increased bending moments compared with what is experienced when floating in smooth water. But not only have these greatly augmented bending moments to be provided for in the structure of the vessel, but, owing to the rapid passage of the waves, the suddenness with which an excess of weight over buoyancy is succeeded by an excess of buoyancy over weight, and vice versâ, conduces to the severity of the stress experienced by the hull, and must receive due attention from the naval architect. In making the calculations necessary in order to arrive at a fair approximation (absolute accuracy being impossible) to the bending moment experienced in wave water, two conditions which probably produce the greatest extreme bending moment to which a ship is likely to be subject, are usually taken.

(1) When supported upon a wave at the middle of the length with consequently greatly reduced buoyancy at the ends, the tendency is for the vessel to 'hog,' as illustrated in fig. 29, p. 69. (2) When the ends are supported upon wave crests, with consequently greatly reduced buoyancy at the middle of the length. In this case, the tendency is for the vessel to 'sag,' as illustrated by fig. 30, p. 70.

In making the calculation in each of these cases, the designer constructs upon the profile of the vessel, as accurately as possible, a geometrical wave form, the height of which is usually taken as $\frac{1}{20}$th of the length measured from crest to crest. Having satisfied himself as to the form of the wave, he must now carefully ascertain that the displacement is exactly equal to that for the still water condition. This must be rigidly observed, for whatever be the contour of the wave water, the volume immersed must remain unchanged as the weight of the ship remains unaltered.

The steps in the calculation are now similar to those followed for the bending moment in still water.

MOMENT OF INERTIA OF ACTUAL SHIPS.

Comparison of Vessels.—As stated at an earlier stage, the standard of strength required in any vessel in order to obtain the freeboard stipulated in the Board of Trade Freeboard Tables, must be at least equal to the structural strength of ships as defined and specified in Lloyd's Rules of 1885.

Fig. 42 is a midship section of a vessel which fully complies with such requirements.

Now while it is demanded that this vessel be at least equal in strength to the standard, it does not follow that the scantlings will be identical in every detail. The true comparison of vessels of *similar dimensions* and form should be made upon the moment of inertia of the weakest section in the neighbourhood of amidships, assuming that the material has been intelligently distributed.

Disposition of Material.—Any addition of material to the section of a girder will produce an increase in its moment of inertia. But we have already seen that such increase is most rapidly obtained by making the addition to the upper and lower extremities.

On turning to the ship girder, the same principle is equally true. For example, in designing the structural arrangement of a vessel, the thickness of the shell plating might be kept uniform from keel to gunwale, and the necessary moment of inertia obtained. But it is plain that an undue amount of material may have been introduced into the structure, for probably the same moment of inertia could have been obtained by reducing the side plating from bilge to sheer strake, and perhaps in some degree from keel to bilge, by making a substantial addition to the thickness of the sheer strake, or by doubling it in certain cases, and perhaps increasing the thickness of the strake below the sheer strake, say $\frac{1}{20}''$. It might also be advisable, in large long vessels, to increase the thickness of bilge plating in one or two strakes. What we have proposed is simply to rearrange the material in the girder section, by adding to the sectional area of the upper and lower extremities, which is the most effective means of increasing the moment of inertia, and permits of a reduction in the thickness of the remaining plating which is nearer to the neutral axis. By this means, an ultimate saving in weight is obtained without any loss in strength or general efficiency. This is a most important consideration to the shipowner, for reduced weight of hull means to him increased deadweight capacity and freight.

In vessels of special design, with particularly light shell plating, caution would be necessary in carrying out any such plan as proposed above, for the absurdity of unduly reducing the thickness of the plating between the sheer strake and bilge in order to effect a saving in weight, and at the same time to promote the possibility of the plating

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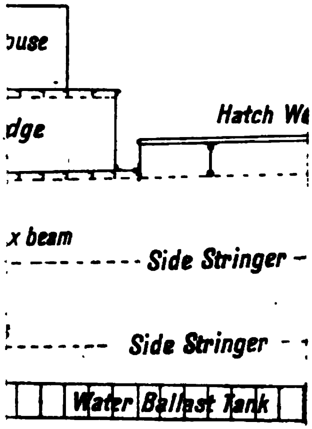
y Deep Framing.



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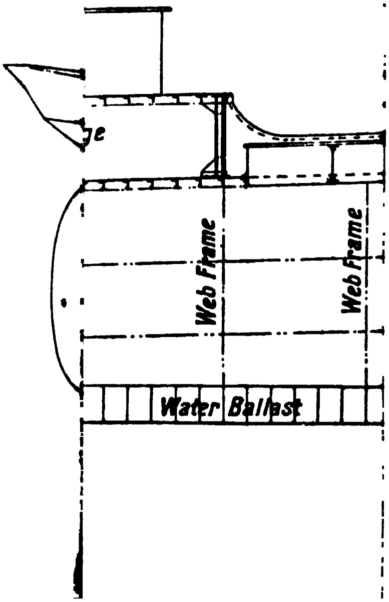

e
Web Frame
Web Frame
Water Ballast

collapsing in the region of the neutral axis when subject to racking stress, is obvious.

A fairly good motto to follow in ship designing is 'Minimum weight to obtain maximum efficiency and strength.' So long as the standard of strength is secured, both the classification societies and the Board of Trade are satisfied, no matter how material may have been wasted, and unnecessary weight introduced by an incapable designer. It must not be overlooked, however, that exceptional strength is required in certain localities to provide for local requirements.

Effect of modification in depth of Transverse Frames.—The vessel in fig. 42 (see also fig. 12) is built on the deep frame system by which hold beams are dispensed with. The transverse framing is made up, over three-fifths of the middle of the length, of two angles each $5 \times 3 \times \frac{8}{20}$. (See fig. 44.)

Now suppose the designer or shipbuilder finds that for some reason or other it is necessary to adopt angles of different scantling, which may affect the thickness, or perhaps alter the depth of the frame girder. Though the common system is to secure the same sectional area of material as in the original section, it must be evident that with such variations in form as just described, a difference in the capacity of the frame to resist bending may have arisen, owing to reduced moment of inertia. Strictly, then, the comparison should not be made upon the sectional area of the material, but upon the moment of inertia of the section.

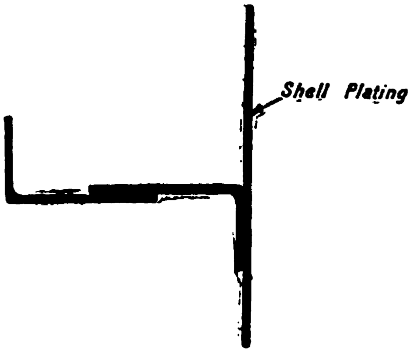

Fig. 44.—Section of Deep Framing.

Further, the more correct method is to calculate the moment of inertia of the frame girder about an axis passing through the heel of the bar upon the shell plating, for the frame being assisted in its stiffness to resist bending by the shell plating for half a frame space upon each side of the frame, the neutral axis of the shell plating, together with the frame girder, comes nearer to the heel of the frame bar than the true neutral axis of simply the two angles forming the frame girder.

Value of Stress Calculation.—It is impossible to make any strength calculation which will give as a result the *actual* maximum tensional, torsional, or compressive stresses endured by any vessel even where accurate information is furnished regarding the distribution of the cargo or the weight. First of all, the severest bending moments are only experienced in wave water, and while it is possible to arrive very closely at an accurate curve of weights, the process of defining the buoyancy is purely tentative.

A curve showing the total buoyancy is easily constructed, but a curve showing the distribution of buoyancy as actually experienced in a seaway, is not so easily obtained, and at best is only an approximation. However, the distribution of buoyancy usually chosen in making the calculation (*i.e.* vessel supported at amidships upon a wave of her own length, and the wave height $\frac{1}{25}$th of the length, crest to crest; or upon a wave of her own length, the hollow being at amidships) is probably worse for the ship than the most extreme condition actually encountered, and the bending moment so obtained is the severest ever likely to be experienced.

On coming to the moment of inertia at a section of the vessel where the bending moment is greatest, and the section weakest — which will generally be in the neighbourhood of amidships — though in ordinary practice no deduction is usually made for rivet holes in the weakest section, still, whether such deductions are or are not made in order to obtain the truest results, the assumption that the workmanship is of a thoroughly reliable and trustworthy character is always made. It must also be assumed that an intelligent disposition of butts has been adopted in the strakes of shell and deck plating and other parts, and that the butt connections are of a thoroughly satisfactory nature.

Taking the calculation, therefore, in its entirety, the tensional or compressive stresses deduced may be other than accurate. Then the question may be asked—Of what use is the performance of so laborious a calculation? In the first place, it is a fair approximation to accuracy, and most probably does not err on the side of leniency, but produces a calculated stress which is larger than that actually experienced under the most trying circumstances at sea.

But its best use lies in its efficiency as a means of comparison. For example, having a standard of strength for a particular freeboard—which at present is that provided by Lloyd's Rules for 1885—in designing a new vessel independently of Lloyd's or any other rules, by a comparison of the maximum tensile and compressive stresses from the two sets of scantlings, the efficiency of the designer's scantlings as compared with the strength standard may be estimated.

Assuming that it is equivalent, it will be further advisable to compare the weight of one foot of midship length for each vessel, as it will be clear that equivalent strength obtained by means of a greater weight of longitudinal material is a most serious objection, resulting, as it does, both in increased cost of vessel and reduced deadweight, while there is nothing to recommend it. The best and most scientifically designed vessel is that in which the lightest material is so disposed and combined as to produce the greatest strength, that is, the least stress.

Or again, where minimum freeboard, as specified by the Board of Trade Freeboard Tables, does not form an item in the designer's consideration, as, for instance in the case of light high-speed channel or river passenger steamers, the comparison may be made apart altogether from any such standard of strength as imposed by Lloyd's 1885 Rules.

Thus, having a light type of high-speed passenger steamer which, after years of life at sea, has proved herself thoroughly efficient in structural strength, the maximum calculated stresses may reasonably be used in making a comparison of strength for a new similar type of vessel.

Calculation for Position of Neutral Axis and Moment of Inertia of an actual Ship.—The following calculation is for the moment of inertia of the section of the vessel shown in fig. 42. It is scarcely necessary to explain that only continuous longitudinal material is dealt with in such a calculation.

CALCULATION TO FIND NEUTRAL AXIS.

Name of Part.	Sectional Area in sq. in.	Distance of Centre of Gravity above Keel in feet.	Moment.
Keel plate,	12·6	0·0	0
Garboard strake,	19·8	0·0	0
Bottom plating,	60·0	·3	18
Bilge ,,	49·8	1·8	89·6
Side ,,	84·0	11·0	924
Sheer strake,	22·6	18·6	420·3
Deck stringer plate,	17·0	19·3	328·1
Gunwale bar,	4·0	19·3	77·2
Deck plating,	33·1	19·6	648·7
Centre keelson,	8·1	1·5	12·1
Centre keelson bottom angle,	4·0	·15	·6
,, ,, top ,,	3·2	2·8	8·9
Side keelson,	10·9	1·6	17·4
Margin plate,	7·5	2·0	15·1
Tank side angle,	2·8	·8	2·2
Tank top centre strake,	7·2	3·0	21·6
,, remainder,	50·4	3·0	151·2
Upper side stringer plate,	8·0	12·0	96·0
,, bulb angles,	16·9	12·0	202·8
Lower side stringer plate,	8·0	5·8	46·4
,, bulb angles,	16·9	5·8	98·0
	446·8		3178·2

$\frac{3178{\cdot}2}{446{\cdot}8} = 7{\cdot}1$ ft. Distance of neutral axis above keel.

It will be seen that the calculation for moment of inertia of any section of a vessel does not involve any serious amount of labour. It is divided into two parts. In the first, the neutral axis is found, the moments being computed relatively to a base line passing through the top of the keel. This is necessary, as explained in the foregoing pages, in order to find the moment of inertia in the second stage of the calculation.

Estimate of Bending Moment for an actual ship, and Stress per square inch.—But before the stress upon either the top or bottom sides

CALCULATION of MOMENT of INERTIA of a vessel when supported upon wave crest at middle of length, and thus subject to Hogging Strain.

Particular Item in Ship Girder.	Sectional Area =A. Sq. in.	Distance of Centre of Gravity from Neutral Axis=h.	h^2	A × h^2	Depths of Vertical webs = d.	d^2	$\frac{1}{12}$ × A × d^2
		ft.			ft.		
Keel plate, ...	*12·6	7·1	50·4	635·0	0	...	...
Garboard strake, . .	19·8	7·1	50·4	997·9	0	...	...
Bottom plating, . . .	60·0	6·8	46·2	2772·0	0	...	...
Bilge „ . . .	49·8	5·3	28·0	1394·4	4·2	17·6	73·0
Side „ . . .	84·0	3·9	15·2	1276·8	14·0	196·0	1372·0
Sheer strake, . . .	22·6	11·5	132·2	2987·7	2·9	8·4	15·8
Deck stringer plate, . .	17·0	12·2	148·8	2529·6	...	...	...
Gunwale bar, . . .	4·0	12·2	148·8	595·2	...	...	...
Deck plating, . . .	33·1	12·5	156·2	5170·2	...	...	...
Centre keelson, . . .	8·1	5·6	31·3	253·5	3·0	9·0	6·0
Centre keelson bottom angle,	4·0	7·0	49·0	196·0	...	...	...
„ top „	3·2	4·3	18·4	58·8	...	...	...
Side keelson, . . .	10·9	5·5	30·2	329·1	2·6	6·7	6·0
Margin plate, . . .	7·5	5·1	26·0	195·0	1·8	3·2	2·0
Tank side angle, . . .	2·8	6·3	39·6	110·8	...	...	...
Tank top centre strake, .	7·2	4·1	16·8	120·9	...	...	...
„ remainder, . .	50·4	4·1	16·8	846·7	...	...	...
Upper side stringer plate, .	8·0	4·9	24·0	192·0	...	...	...
„ bulb angles, .	16·9	4·9	24·0	405·6	...	...	...
Lower side stringer plate, .	8·0	1·7	2·8	22·4	...	...	...
„ bulb angles, .	16·9	1·7	2·8	47·3	...	...	...
				21136·9			1474·8
				1474·8			
				22611·7	Moment of inertia for half section.		
				2	For both sides of vessel.		
				45223·4	Total moment of inertia.		

of an actual ship can be ascertained, the bending moment has to be found. This, as previously shown, is a very laborious and lengthy process of calculation. But happily, for ordinary types of vessels of usual proportions, whether cargo or passenger, $\frac{1}{35}$th of the length on the load water-line multiplied by the displacement in tons is found to give a fairly accurate approximation to the maximum bending moment experienced, and which is developed when the vessel is supported upon the crest of a wave at amidships, and enduring a 'hogging' strain. This is the bending moment usually adopted by designers in making stress calculations. For certain

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* The sectional areas in the above calculation are for one-half of the section of the vessel. It is thus necessary to multiply the moment of inertia for the half section by 2 in order to obtain the total moment of inertia.

special types of vessels, the fraction of the length may drop as low as $\frac{1}{25}$th or even $\frac{1}{24}$th. But, as just stated, for the comparison of ordinary types of vessels, $\frac{1}{35}$th of the length is generally taken.

The vessel whose midship section is shown in fig. 42, and moment of inertia calculation on previous page, is 240 ft. long, 35·5 ft. extreme breadth, and 16 ft. draught. Coefficient of fineness ·72.

The displacement is:—

$$\frac{240 \times 35{\cdot}5 \times 16 \times {\cdot}72}{35} = 2804 \text{ tons displacement,}$$

$$\text{and } \frac{240 \times 2804}{35} = 19227 \text{ maximum bending moment.}$$

The neutral axis being 13·1 ft. from top of sheer strake, and 7·1 ft from the keel, *the maximum tensional stress on the top of the sheer strake* will be—

$$\frac{19227 \times 13{\cdot}1}{45223{\cdot}4} = 5{\cdot}5 \text{ tons per square inch,}$$

and the *maximum compressive stress on the bottom plating* will be—

$$\frac{19227 \times 7{\cdot}1}{45223{\cdot}4} = 3 \text{ tons per square inch.}$$

On account of the heavier massing of longitudinal material along the bottom and bilge of a vessel, the neutral axis is generally considerably nearer to the bottom of the vessel's section than the top. Consequently the stresses are usually severest on the topsides. The great value of steel upper decks is not only that they increase the moment of inertia of the section, but that they raise the neutral axis also, and thus reduce the excess of stress upon the topsides.

Value of Registration Societies to Shipowners.—The custom is so prevalent in these days for shipowners to class their vessels in one or other of the registration societies, that the shipbuilder, not being responsible for the structural strength, seldom finds it necessary to calculate the stresses, except in the case of special types of vessels not built to any class.

It naturally follows that the most extensive, varied, and valuable of such information must be held by the registration societies, who are directly responsible for the strength of the vessels built to their requirements. With their wide and diversified experience of vessels of all types, including the enormous value of periodically coming into contact with vessels which have to be surveyed and carefully examined in order to maintain their class, no all-round judgment can be more authentic or valuable than theirs.

Comparison of Stresses on Vessels increasing in Size.—The late Mr. John, of Lloyd's Register, as the result of most extensive investigation into the strength of ships, gave the following particulars of calculated stresses for vessels increasing in size, and which are known to have proved thoroughly efficient.

Register Tonnage of Vessel.	Maximum Tensile Stress per square inch upon Upper Part of Section.
100	1·67
200	2·36
400	3·55
600	3·72
800	4·59
1000	5·19
1500	5·34
2000	5·9
2500	7·08
3000	8·09

The proportions of the above vessels were about eight breadths and eleven depths in length, and they were each equal to Lloyd's highest class at that time. The maximum bending moment, when supported upon a wave crest at the middle of the length, was assumed to be $\frac{1}{35}$th of the length multiplied by the displacement. As the proportion of length to breadth and to depth increases, the stresses increase, and similarly, when the proportion decreases, the stresses decrease also.

Though Mr. John's stress results were published in 1874 for *iron* vessels then in service, subsequent calculations made upon modern vessels do not widely differ from these results, which still remain both valuable and interesting.

In 1892, Mr. A. Denny, in a short, but very valuable paper read before the Institute of Naval Architects, showed that, for a typical vessel, 350′ × 44′ × 32′, with a displacement coefficient of fineness varying from ·56 to ·78, loaded with homogeneous cargo, and bunker coal consumed at the end of a voyage of 5000 nautical miles, the maximum hogging stresses upon waves equal to the length of the vessel, and of a height equal to $\frac{1}{20}$th of their length, ranged between 7·93 and 9·76 tons per square inch. For a smaller vessel, 250′ × 30′ × 23′, Mr. Denny also showed that with displacement coefficients of fineness of ·637 and ·795 under similar conditions, excepting that the length of the waves was equal to the length of the vessel, and their heights equal to $\frac{1}{25}$th of their length, the maximum calculated hogging stresses were 4·28 and 5·57 tons per square inch respectively.

It is observed from the foregoing results of calculated stresses, that the maximum stresses upon small vessels are very much smaller than the maximum stresses upon large vessels of similar proportions. From a purely strength of girder point of view, such wide disparity in stresses should not exist, but while ships may, in some respects, be treated as, and compared to girders, they are very much more than ordinary girders. The exceedingly wide diversity of the demands made upon the strength and stiffness of ships, which in many instances have to be met in small vessels to an almost equal extent as in large vessels, necessitates the introduction of much more material than the demands upon a simple girder would entail, and as a result, the calculated stresses in small vessels are comparatively small.

Further Remarks upon the Value of Stress Calculations.—As we have pointed out and explained at an earlier stage, the calculated stresses must not on any account be taken as the actual stresses experienced by ships in performing their work at sea. As a matter of fact, we have no means of ascertaining what the actual stresses are which a ship endures. At the same time, all such calculations should, as far as it is possible, approach the truth. In most stress calculations made for vessels supported amidships upon a wave crest, and upon wave crests at their ends with the wave hollow at amidships, it is usual to consider the water pressure at equal depths in all parts of the wave crest and hollow as though it were exactly the same as in smooth water. But this is not the case. The upward heave of the wave reduces the weight of the particles of water in the waves, and consequently varies their still water upward thrust, while the water in the wave hollow, being below the normal level (remembering that in waves it is the *form* only that travels, the water itself only rising and falling), exerts a pressure varying in the opposite way. These variations of pressure in wave water naturally have their effect upon the buoyant supports given to the vessel, and certainly modify the results obtained by considering the vessel to be among wave water, the pressure of which at similar depths below all points of the surface is assumed to be equal.

To introduce all such modifying agencies as these into the calculation would mean enormous labour, and while it is very unusual to consider them in making an actual calculation, it is well to remember that they do exist.

As previously shown, the great value of all calculated stresses lies in their value as a means of comparing vessels of similar types.

Although in a steel structure, where a stress is gradually and steadily applied and as gradually removed, to expect the material to stand a working stress of 9 or 10 tons per square inch would be quite reasonable when it is of good uniform quality similar to that used for ship construction and the workmanship is of the most efficient character, yet in many steel structures, and particularly in ships, the stresses experienced are most irregular, and often for considerable periods when labouring in a seaway, applied in the most sudden manner.

How true this is must be very clear when it is remembered that in the rapid transit of waves during the period of a few seconds, a severe tensile stress is converted into a compressive sagging stress, and this goes on indefinitely. Under such circumstances, it is most important that the material be not taxed to any such limit as may be considered safe under a steadily applied stress.

Working Stress.—Taking the factor of safety of steel as 5, the maximum working stress should not exceed $\frac{30 \text{ or } 32}{5} = 6$ to 7 tons. But as vessels with a *calculated* maximum stress of 8 tons and over are doing service without showing any signs of weakness, the natural inference is, that calculated stresses are in excess of those actually experienced, which is undoubtedly the case, for probably part of the assumptions made for extreme conditions, in calculating the maximum stresses, are never actually experienced.

However, whenever stresses work out, in cargo vessels, to between 8 and 10 tons, and in some cases even more than this, special attention should be given to the strengthening of the top and bottom flanges of the ship girder.

Erections on Deck.—Though short poops, short bridges, and short forecastles increase the depth of the ship girder locally, they add no material longitudinal strength to a vessel. Isolated strength may be necessary to meet a local strain, and short erections may serve a certain purpose, but these do not improve the strength of the ship girder as a whole. Indeed, where short bridges are built, the sudden termination of strength at their ends makes a decided weakness in the longitudinal strength, especially when subject to the sudden and severe stresses experienced in wave water (the maximum bending moments, it is remembered, being greatest over the middle of the length), and if no provision were made to cover this, signs of severe straining might be expected at the ends of such bridges,—in the sheer strake and side plating and the deck stringer. This would show itself in opened butt joints, sheared rivets, or, perhaps, serious deflexion as illustrated in an exaggerated manner in figs. 29, 30, 31, and 32. Therefore the extra strength afforded by the bridge, or any other erection terminating on the midship half length, must be blended into the hull proper. This is usually done by doubling the sheer strake for some distance at each end of the bridge, by doubling or thickening the deck stringer in the same locality (or both methods), and by carrying the lower strake of the bridge side plating, which is generally thicker than the bulwark plating, for some distance beyond the bridge at each end, thereby forming part of the bulwark plating Neither *short* poops, bridges, forecastles, nor the extra means for strengthening vessels at the ends of bridges or other midship erections are taken account of in calculating the moment of inertia of the section, and in estimating the stress upon the upper and lower parts of the section.

Where, however, a long bridge is fitted, covering at least $\frac{3}{5}$ths of the midship length of the vessel, it affords very material longitudinal strength. Certainly it does not cover the whole length of the vessel, but it extends over that part of the length upon which the severest bending moments are experienced. It is right, therefore, that such a bridge should be included in calculating the longitudinal strength of the vessel, provided that care be taken to avert the sudden termination of strength at the bridge ends in a manner similar to that described for the ends of short bridges.

Similar precautions must be taken in dealing with all other erections which terminate anywhere on the middle length of the vessel. Thus, raised quarter decks which terminate on the middle length, and are not connected with any other erections, require special attention at the end. Not only are the precautions necessary as explained for short bridges, but the two lengths of the ship of different depths are strengthened at the break by overlapping their decks for several frame spaces, and uniting the overlapping parts by diaphragm plates. (See fig. 47.)

Without such preventive means, injury such as described at the ends of short bridges might be anticipated. Similar steps are necessary when the raised quarter deck terminates against a bridge. The broad principle to be kept in view is, that all sudden terminations in strength must be rigorously avoided. In making calculations for strength, a section should be chosen where the bending moment is greatest and the transverse section weakest; and only such longitudinal material as contributes substantial structural value to the ship girder should be taken account of in the calculation.

Board of Trade Instructions for Comparing the Strength of Vessels for Freeboard Purposes.—In making calculations of strength in order to make a comparison for freeboard purposes, the Board of Trade instructions state that steel or iron decks which cover not less than $\frac{4}{5}$ths of the midship length of the vessel are to be considered in the calculation just as they would be if of the full length.

Wood weather decks, if continuous throughout the midship portion of the ship, are to be considered as equivalent to steel of $\frac{1}{25}$th the sectional area of the wood.

For the purpose of comparison of strength, the breadth of the hatchways in the standard vessel is deemed to be $\frac{1}{3}$rd the breadth of the deck, and the tie plates are assumed to be fitted at the sides of the hatchways. A deduction of $\frac{1}{7}$th is to be made for rivet holes in steel, and $\frac{1}{8}$th in iron for the parts under tension.

Deductions.—After the consideration we have given in the foregoing pages to the strength of ships, a brief enumeration of a few deductions from facts which must now be fairly obvious will appropriately conclude this section.

1st. Vessels of great length require more longitudinal strength (larger moment of inertia of cross section) than vessels of less length, even though of identical transverse dimensions, simply because increased length, and, in all probability, increased displacement, produce an augmented bending moment.

The classification societies provide for this by demanding additional longitudinal strength in vessels of extreme proportions.

2nd. Long shallow vessels with their small depth of girder, and hence small distance from neutral axis to upper and lower extremities, are greatly handicapped, as it were, in producing a satisfactory moment of inertia of cross section sufficient to provide for the demands which may be made upon their strength when subject to maximum hogging and sagging bending moments.

While long shallow vessels of comparatively light scantlings may be safely used for passenger service in rivers and channels, it is obvious that, without extraordinary additions to their scantlings, they are totally unfit for over-sea trade, and more especially so, if required to carry miscellaneous cargoes. In such vessels, continuous longitudinal middle line bulkheads afford most valuable longitudinal strength.

3rd. In all vessels, more transverse strength is required in the region of amidships than elsewhere. This is apparent when it is remembered that the girth is greatest here, with consequently maximum pressure from the water. Transverse framing should therefore be of extra strength over the middle length (usually $\frac{3}{5}$ths length).

The maximum hogging and sagging bending moments also are greatest over the middle length of ships, and all longitudinal material should therefore be of extra strength over this locality (usually the half length).

The special weakness caused by hatchways and other deck openings, and openings in side plating, and the means which may be adopted for providing the necessary strength, is considered in the chapter on 'Structure.'

CHAPTER VI.

TYPES OF VESSELS. SECTION I.

Fundamental Types and Modifications of same—Relation between Deck Erections and Deadweight—No Reduction in Freeboard for Excessive Strength in a vessel with Full Scantlings—Determination of Type—Three Deck, One and Two Deck, Spar and Awning Deck Vessels—Illustration of Principal Scantlings of foregoing types—Vessels of Intermediate Grades between Three Deck and Spar Deck, and Spar Deck and Awning Deck — Raised Quarter Deck Vessels — Maximum Stress—Partial Awning Deck, Shelter Deck, Well Deck, Shade Deck Vessels, etc.

Fundamental Types of Vessels.—The great variety of purposes for which ships are used, and the widely different kinds and densities of cargoes which may be carried, have had the very natural effect of producing vessels specially adapted for specific purposes. And thus, while ordinary mercantile steamers may generally be classed under the heading of cargo or passenger steamers—wholly or partially—much greater subdivision of type is adopted. Hence ship-folk are in these days familiar with the three principal or fundamental types of vessels—

(1) *Vessels of full scantlings, known as Single, Two, or Three Deck,*
(2) *Spar Deck Vessels,*
(3) *Awning Deck Vessels,*

and also with modifications of these types, such as *Raised Quarter Deck Vessels, Partial Awning Deck Vessels, Shelter Deck Vessels, Shade Deck Vessels,* and in addition, vessels of more novel type, such as '*Turret,*' '*Trunk,*' and other '*Self-trimming*' steamers.

In this section it is purposed, by means of description and illustration where necessary, to point out the special features in either design or structure which produce the distinctions in these different types.

We have previously shown, in dealing with the subject of classification, that the load line is assigned to a vessel strictly in proportion to her structural strength with a minimum percentage of reserve buoyancy. This, it will be understood, applies to every kind of vessel to which a minimum freeboard is assigned.

Relation between Deck Erections and Deadweight.—Now, assuming that a flush deck vessel has been built to the highest standard of structural strength, it will follow that no reduction can be made in the freeboard unless additional reserve buoyancy, suitably situated, can be added to the vessel. But as valuable additional buoyancy can be obtained in the form of forecastles, bridges, poops and other superstructures covering either the whole, or part of the length of the vessel, reductions in freeboard, which may considerably augment the deadweight carrying capacity of the vessel, are obtained.

No reduction in freeboard for excessive strength in a vessel of full scantlings. Again, taking the case of a flush decked vessel (with no erections whatever) built *in excess* of the highest standard of structural strength, no concession could be obtained in the matter of freeboard, simply because, as we have pointed out, such a vessel would have a less percentage of reserve buoyancy than required by the freeboard tables of the Load Line Act of 1890. And as seaworthiness embraces other features in addition to structural strength and equally important, to jeopardise the safety of a vessel by allowing to her the maximum immersion which a consideration of her structural strength alone would permit, would be exceedingly unwise. One of these important features which is vastly influenced by the amount and disposition of the reserve buoyancy is the stability, and in drawing up the 'Freeboard Tables,' a minimum percentage of reserve buoyancy was specified for flush decked vessels of ordinary type and proportions, such as, it was assumed, would ensure as far as possible, favourable stability conditions when properly loaded.

With these points kept in view, together with what has already been said upon 'Classification,' we shall better be able to see how the different types and modifications of types of vessels have arisen.

The Determination of Type.—Every reader knows that there are many bulky cargoes of such comparatively small density that a vessel could be loaded up to her hatches, and every available space in deck erections occupied, and the total deadweight would not be sufficient to immerse her to the maximum draught; while, on the other hand, there are other cargoes of vastly greater density with which the same vessel could be brought to her load draught long before the total hold space had become occupied. To such variations in the specific gravity of cargoes are principally due the types known as awning deck, spar deck, and vessels of full scantlings.

Three Deck Vessels.—Let us first suppose that a shipowner contemplates the addition of a new vessel to his fleet. We now see that he has more to consider than merely external dimensions and speed. He must be satisfied in his own mind, to some extent at any rate, as to what is the most probable kind of cargo this vessel will carry. If the probable cargo be of considerable density, it will naturally follow that it will be impossible, as with many of such cargoes, to fully occupy the whole hold space before the vessel has reached her load water-line. He will therefore want that type of vessel which will carry the greatest deadweight in relation to her size, and as we have seen, the strongest type of vessel built and that which permits of the greatest immersion (*i.e.*, to which the least freeboard is assigned), is that known as the 'three deck' vessel, though it is not actually necessary, as before shown, that the vessel should possess three actual tiers of beams, for the lowest tier may be dispensed with by introducing compensation in the form of deep framing, web framing, etc., and, under some circumstances, even the middle deck (if only required to be of wood) may be dispensed with, the beams only remaining.

One and Two Deck Vessels.—Vessels of smaller size, though built to the fullest scantlings, may only require two, or even one tier of beams.

The amount and nature of erections on vessels of this kind, as for Three Deck vessels, would probably depend chiefly upon the requirements for the accommodation of the crew, protection of steering gear, and, as in the case of Three Deck vessels, upon the proportions chiefly in relation to the depth to length. Even in the case of erections such as those just mentioned, considerable reduction may be obtained in the freeboard (which means increased deadweight) according to the value of the reserve buoyancy afforded by such erections.

Awning Deck Vessels.—Supposing, again, that the shipowner required a vessel to carry cargo of comparatively light density, or say, to carry cargo in the lower holds with passengers in the 'tween decks and other superstructures, it is obvious that the three decked vessel of full scantlings would be unsuitable for the purpose, for not only would he find it impossible to bring the vessel down to her load draught line with ordinary miscellaneous cargo, but the excessive strength of the vessel would have entailed much unnecessary outlay in the first cost, for excessive and therefore unnecessary structural material is both useless and waste. Under such circumstances the light awning deck type of vessel would probably be adopted, which, possessing large freeboard, that is, high side out of water, would have the additional advantage of being drier on deck, and therefore better adapted to the comfort and requirements of passengers.

Spar Deck Vessels.—Intermediate between the three deck vessel of full scantlings and the awning deck vessel of greatly reduced scantlings, comes the spar deck type of vessel, which is particularly suited for cargoes of moderate density. In recent years this type has been extensively adopted. All other vessels, whether they be called shelter deck vessels, shade deck vessels, raised quarter deck vessels, partial awning deck vessels or vessels of special design for self-trimming purposes, may, from a structural point of view, be assigned to one of the fundamental types, though modified in certain of their structural features in a greater or less degree.

The external view of the structure of a vessel, such as may be obtained as she lies afloat unloaded, or in dry dock, affords little indication whether she be of three deck, spar deck, or awning deck type. However, in a fully loaded condition, the amount of freeboard would present a more certain clue to the determination of her type.

Closer Examination of Types.—It will be necessary at this stage to examine the structural features of these different types of vessels in more minute detail.

Vessels of Full Scantlings.

First. One and Two Deck Type.—See fig. 45, which is a midship section of a single deck vessel.

See also fig. 10, which is a midship section of a two deck vessel, built with ordinary frames and widely spaced hold beams; fig. 11, which is a midship section of the same vessel with web frames compensating for hold beams; and fig. 12, which is also the same vessel built with deep framing, likewise dispensing with hold beams.

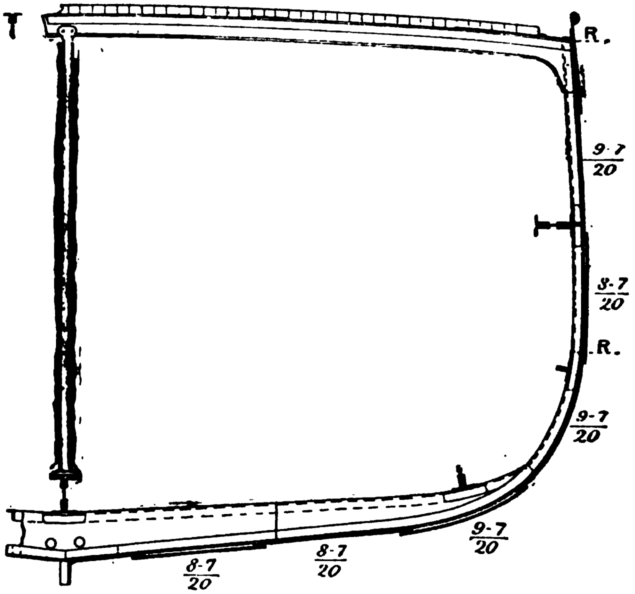

Fig. 45.—Midship Section of a Single Deck Vessel.

The sectional profile of the two deck vessel shown in fig. 46, is for the same vessel to whose midship section we have just referred in fig. 12.

The following Tables of Scantlings for figs. 10, 11, and 12 (and 46) will give to those readers unacquainted with the rules of the classification societies, some idea of the sizes of material required for vessels of this size. The scantlings are such as would comply with Lloyds' present requirements for 100 A1 class.

Scantlings for Fig. 10.	Scantlings for Fig. 11.	Scantlings for Fig. 12.
Lloyd's Numerals*—		
½ Girth, . . 34·4	Same as for fig. 10.	Same as for fig. 10.
½ Breadth moulded, 17·75	,, ,,	,, ,,
Depth, . . 20·00	,, ,,	,, ,,
1st number, . 72·15	,, ,,	,, ,,
Length, . . 241	,, ,,	,, ,,
2nd number, . 17,388·15	,, ,,	,, ,,
Depth in length = 12·05.	,, ,,	,, ,,
Frames, 4½ × 3 × $\frac{8-7}{20}$.	Frames outside tank, 4½ × 3 × $\frac{8-7}{20}$. Web frames, 15 × $\frac{8-7}{20}$; angles, 3 × 3 × $\frac{7}{20}$ six frame spaces apart (12 ft.). Frames in double bottom, 3 × 3 × $\frac{8-7}{20}$.	Depth of frames 7 in., composed of two angles, 5 × 3 × $\frac{8-7}{20}$.
Frame spacing, 24 in.	Same as for fig. 10.	Same as for fig. 10.
Reverse frames, 3 × 3 × $\frac{7}{20}$.	,, ,,	See frames.
Floors, 22½ × $\frac{9}{20}$.	Floors, 35 in. deep × $\frac{7}{20}$.	Same as for fig. 11.
Centre keelson, 17 × $\frac{12-10}{20}$.	Centre through-plate, 44 × $\frac{9}{20}$.	Centre through-plate 35 × $\frac{9}{20}$.
,, angles, 5 × 4 × $\frac{9}{20}$.	Top angles, 4 × 4 × $\frac{8}{20}$.	Top angles, 4 × 4 × $\frac{8}{20}$.
Rider plate, 11 × $\frac{12}{20}$.	Tank margin plate, 21 × $\frac{7}{20}$.	Bottom ,, 5 × 4 × $\frac{9}{20}$.
	Tank top centre strake, 36 × $\frac{8-7}{20}$.	Same as for Fig. 11.
	Tank top under engines and boiler, $\frac{8}{20}$.	,, ,,
	Tank top in holds, $\frac{7}{20}$.	,, ,,
Side intercostal, $\frac{8}{20}$.	Side intercostal, $\frac{7}{20}$.	,, ,,
,, angles, 5 × 4 × $\frac{9}{20}$.	,, angles, 3 × 3 × $\frac{7}{20}$.	,, ,,
Bilge keelson bulb plate, 9½ × $\frac{9}{20}$.	Formed by margin plate.	Same as for fig. 11.
Bilge angles, 5 × 4 × $\frac{9}{20}$.		
Side stringer, } 5 × 4 × $\frac{9}{20}$. Two angles, }	{ Two side or web stringers, 15 × $\frac{8-7}{20}$. { Angles, 3 × 3 × $\frac{7}{20}$.	Two side stringers. Plate, 16 × $\frac{10-9}{20}$. Bulb angles, 9 × 3½ × $\frac{13-12}{20}$, or, alternate method, Plate, 20 × $\frac{8-7}{20}$. Angles, 5½ × 4 × $\frac{9}{20}$.

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* See page 47 for explanation of numerals.

TABLES OF SCANTLINGS—*continued.*

Scantlings for Fig. 10.	Scantlings for Fig. 11.	Scantlings for Fig. 12.
Upper deck beams, $5\frac{1}{2} \times 3 \times \frac{8}{20}$. Bulb angle. 2 ft. apart.	Same as for fig. 10.	Same as for fig. 10.
	Whole beams at head of web frame, $8 \times \frac{8}{20}$ bulb plate and two angles, $3 \times 3 \times \frac{6}{20}$.	,, ,,
Lower deck beams, $9\frac{1}{2} \times \frac{9}{20}$. Bulb plate. 18 ft. apart.	None.	None.
	,,	,,
Angles, $4 \times 4 \times \frac{8}{20}$.	,,	,,
Covering plate, $\frac{8}{20}$.	,,	,,
Upper deck stringer, $34\frac{1}{2} \times \frac{10}{20}$.	Same as for fig. 10.	Same as for fig. 10.
Lower ,, ,, $32 \times \frac{9}{20} - 25 \times \frac{8}{20}$.	None.	None.
Pillars, hold, $3\frac{1}{4}$.	Pillars, $3\frac{5}{8}$.	Same as for fig. 11.
,, 'tween decks, $2\frac{5}{8}$.	None.	None.
Bulkheads, four in number, $\frac{6}{20}$ thick.	Same as for fig. 10.	Same as for fig. 10.
Bar keel, $9 \times 2\frac{3}{8}$.	Keel slabs on sides of centre through-plate 1 in. thick.	Flat plate keel, $36 \times \frac{14-11}{20}$.
Complete steel deck, $\frac{6}{20}$.	Same as for fig. 10.	Same as for fig. 10.
Reverse angles to upper and lower decks alternately.	Reverse angles to upper deck and stringer below alternately.	All reverse angles to upper deck, except in the peaks, where ordinary framing is adopted.
See fig. 10 for scantlings of shell plating.		

A single deck steam vessel, according to Lloyd's Rules, is one having a depth from the top of the keel to the top of the beam at the centre (with the normal round up) of less than 15 ft. 6 in., while a two deck vessel is one of less than 24 ft. depth. As previously shown, the two deck vessel need not necessarily possess two complete decks, for while the upper deck must be a complete deck laid and caulked, the lower deck may only consist of a tier of widely-spaced strong beams, or even these may be dispensed with, if compensation in the form of web frames and stringers, or deep framing be introduced.

The 1st numeral, by means of which is obtained the spacing of the frames, and the scantlings of frames, reversed frames, and floor plates, the thickness of bulkheads, and the diameters of pillars, is determined by adding together in feet the half-moulded breadth of the vessel amidships, the depth at the middle of the vessel's length from the upper part of the keel to the top of the upper deck beams with the normal round up, and the half girth of the midship frame section measured from the centre line at the top of the keel to the upper deck stringer plate.

By multiplying the 1st numeral by Lloyd's length,* the 2nd numeral is obtained, by means of which are ascertained the scantlings of the keel, stem, and stern post, keelson and side stringer plates and angles, the thickness of the outside shell plating; and this 2nd numeral, in conjunction with the proportion of the vessel's length to depth, determines the scantlings of deck stringer plates, thickness and extent of deck plating, and special additions to structural strength which are required when the vessel is of extreme proportions, that is, of over eleven depths to length. All bulkheads extend to the height of the upper deck. When there is an erection in the form of a bridge, poop, or forecastle, all the frames extend to the height of the stringer plate upon the deck of such erections.

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* See page 50.

In vessels with two tiers of beams, the reversed angles should extend alternately to the upper deck stringer plate, and to the top of the continuous angle bar on the hold beam stringer. Should the hold beams be dispensed with and web frames substituted, the reversed frames will extend to the upper deck stringer plate and to the top of the angle bar on the stringer plate next below it. With deep framing both the frame and reversed frame extend to upper deck. In small single deck vessels, where the numeral is less than 57, the reversed frames may extend to a less height than that just given. As such erections as poops, bridges, and forecastles are only considered as superstructures, damage to which it is not supposed would endanger the safety of the vessel, the thickness of side plating and the scantlings of their beams and stringers are less than are required for the main hull of the vessel.

Second. Three Deck Vessels.—In vessels of this type the upper deck is the strength deck. By this we mean that the vessel depends for structural strength upon the material up to and including the upper deck, when she is subject to the various stresses which are experienced in smooth and wave water, in a ballast, or fully or partially loaded condition. The upper deck, moreover, *must* be considered as the strength deck, because, in the event of damage accruing in any part of the structure up to, or including that deck, the safety of the vessel may be greatly imperilled. A three deck vessel is one of 17 ft. or over in depth from the top of the keel to the middle deck at centre (with the normal round up), or 24 ft. or more to the upper deck at centre.

Here, again, these vessels need not necessarily possess three tiers of beams, for the lowest tier may be dispensed with in a manner similar to that described for the two deck vessel. The numerals for scantlings are obtained somewhat differently from the method described for one and two deck vessels. The 1st numeral is obtained by adding together the half-moulded breadth, and the depth and half girth of the midship frame section measured to the *upper* deck. From this sum 7 is deducted, and the result is the 1st numeral. This, multiplied by the vessel's length, gives the 2nd numeral. All bulkheads extend to the upper deck. All frames extend to the upper deck stringer plate, and where poops, bridges, or forecastles are fitted to the height of their respective stringer plates.

When ordinary framing is adopted, the reversed frames extend alternately to the upper deck, and to the angle bar on the middle deck stringer plate. If the vessel has deep frames, each alternate reverse frame may stop at the middle deck angle, unless, as in figs. 48 and 49, the height of 'tween decks exceeds 8 ft., in which case all the reversed frames extend to the upper deck. The sheer strake is placed at the upper deck.

While the original idea of a three deck vessel was one possessing two or more complete decks laid and caulked, and a tier of hold beams, or a substitute for these hold beams, it is now common for some of these vessels to have not more than one laid deck, and whether a steel deck be required will depend upon the size of the vessel's 2nd numeral, and the proportion of depth to length. For example, a three deck vessel, with a 2nd numeral of less than 23,000 and under ten depths in length, or 19,000 and under eleven depths, would require no steel deck whatever; and only when the 2nd numeral had reached 25,000, if there be less than ten depths in the length, would one complete steel deck be required. Where, however, a steam three deck vessel requires not more than one steel deck, the wood middle deck may be dispensed with by making an addition to such freeboard as would be assigned in accordance with the Load Line Act to an ordinary three deck vessel with the middle deck laid. Should, however, the shipowner object to any increase in freeboard, the middle wood deck may be dispensed with if the frames and reverse frames are of a size such as would be obtained from the 1st numeral without the deduction of 7. Moreover, all reverse frames would be required to extend to the upper deck, or other compensation introduced.

The three deck vessel illustrated in figs. 48 and 49 has a shelter deck erection extending all fore and aft, and on the shelter deck a bridge erection. So valuable may the shelter deck be in affording longitudinal strength and buoyancy, especially if it be covered with a steel deck as shown in the diagram, that by estimating its value to the whole ship structure, it may be found to merit important consideration in the determination of the load line. See further remarks upon Shelter Deck Vessels, p. 127.

The dimensions of this three deck vessel are:—Length between perpendiculars, 443 ft.; moulded breadth, 51 ft. 6 in.; depth moulded, 33 ft. 3 in.; 'tween decks, 9 ft. 4 in. Lloyd's 1st number is 108·55, and 2nd number 47,870. There are 12·8 depths in the length. Some idea of the sizes of the material for such a vessel of the highest class, say 100 A1 at Lloyd's, may be obtained from the following particulars:—

The depth of the deep framing is 10½ in., made up of angles $\frac{10-9}{20}$ in thickness.

Frame spacing, 26 in.

The longitudinal stringer intercostal plates are 20 in. broad × $\frac{11}{20}$ and the bulb angles $9 \times 3\frac{1}{2} \times \frac{12}{20}$.

Upper deck stringer plate 67 in. × $\frac{11}{20}$ for half length amidships to 51 in. × $\frac{9}{20}$ at ends.

Upper deck plating $\frac{9-8}{20}$

" " beams, tee bulb, 11 in. × $\frac{10}{20}$.

Middle " stringer 67 in. × $\frac{11}{20}$ to 51 in. × $\frac{9}{20}$.

" " plating $\frac{8-7}{20}$

" " beams, 12 in. × $\frac{11}{20}$ in., tee bulb.

Shell plating. Sheer strake $\frac{3}{4}$ in. (+ $\frac{2}{20}$ as part compensation for sheer strake doubling) to $\frac{12}{20}$ at ends.

Keel 1 in. (+ $\frac{2}{20}$ as part compensation for keel plate doubling).

Garboard strake $\frac{3}{4}$ in. (+ $\frac{2}{20}$ as part compensation for keel plate doubling).

Elsewhere, outside strakes $\frac{14-11}{20}$

" inside " $\frac{13-10}{20}$

Centre through plate in double bottom 48 × $\frac{11-9}{20}$

Floors $\frac{9-8}{20}$

Shelter deck $\frac{6}{20}$ steel, or $\frac{6}{16}$ iron.

" beams, 8 × 3 × $\frac{9}{20}$. Bulb angles on every frame.

Shelter deck side $\frac{9}{20}$ (+ $\frac{3}{20}$ as part compensation for sheer strake doubling) to $\frac{8}{20}$ ends.

By reason of the extreme proportions, a doubling is required to the sheer strake for its whole width. This has been dispensed with, and compensation introduced into the upper side plating, as noted in brackets. Moreover, the shelter deck stringer plate has been made of exceptional strength—$\frac{12}{20}$ths, for the same cause.

In addition to the foregoing, $\frac{2}{20}$ths are required upon the inside strake of shell plating below the sheer strake, and $\frac{2}{20}$ths to the upper deck stringer plate.

It may again be pointed out, that in all vessels of full scantlings, and of very extreme proportions (Lloyd's say 13 depths in length), a substantial erection (bridge) should cover the half length amidships. The structural value of this has been fully treated in Chapter V.

SPAR DECK VESSELS.

First, of ordinary Rule Requirements.—In spar deck vessels, the uppermost or spar deck is the strength deck as in the case of three deck vessels, and for the same reason. As we have previously pointed out, spar deck vessels are of lighter construction than vessels of the same dimensions built to Three Deck rule.

These vessels require to have three tiers of beams, though as shown for vessels of full scantlings requiring two and three decks, the lower tier of beams may be dispensed with, providing that compensation be introduced in lieu of the same.

Though a spar deck vessel may be of the same length and depth to spar deck as for a similar three deck vessel, both the 1st and 2nd numerals are considerably less. The reason for this is, that the half-girth and depth are taken to the main or middle deck instead of to the upper deck as in three deck vessels, with the result that a much smaller 1st numeral is produced, which, multiplied by the length, gives a smaller 2nd numeral. But the proportion of depth to length is also taken to the main deck, and consequently, these vessels are of greater extreme proportions than the corresponding three deck vessel, which may mean considerable additions to structural strength.* However, as it is found that taking the depths to length to the main deck would too severely penalise the spar deck vessel if the rule requirements for additional strength on account of extreme proportion were given, while the vessel has in reality the benefit of the depth between the main and spar decks, a deduction of two depths is allowed. And thus a vessel of, say, sixteen depths to main deck in the length, would be considered in taking out her scantlings as though she were only of fourteen depths.

In spar deck vessels, all the bulkheads required by rule extend to the height of the spar deck. The spacing of the frames, and the scantlings of frames, reverse frames, thickness of bulkheads, depths and thickness of floors, size of bar and flat plate keels, stems, stern posts, keelson and stringer angles, constructive material in double bottoms, thickness of shell plating up to and including the main deck sheer strake, main and lower deck beams, are exactly the same as are required for a two decked vessel of the same dimensions up to the main deck. In short, the vessel up to the main deck is practically similar in construction to a two decked vessel. Having, however, a valuable erection above the main deck, which is not only an indispensable but also an integral part of the ship structure, a reduction of two depths is allowed in the proportion of depths to lengths in consequence as previously described.

All the frames extend to the height of the spar deck stringer plate. The reverse frames should extend to the upper part of the frames and to the top of the angle bar on the main deck stringer alternately. In addition to the spar deck, these vessels must have a complete main deck laid and caulked.

The beams to main and lower decks are of the same scantling as would be required for a two decked vessel. The spar deck beams are lighter than required for the upper deck in three decked vessels. For example, a three deck vessel of 40 ft. in breadth at the upper deck would require beams under a steel deck of bulb angle $7\frac{1}{2} \times 3 \times \frac{10}{20}$, while the beams for a spar deck of similar breadth would be $7 \times 3 \times \frac{9}{20}$.

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* In no case, however, does the structural material in the upper parts of these vessels, and the number and thickness of steel decks, require to be in excess of that specified for the three deck vessel of the same dimensions. In the case of the bilge and bottom, extra strength is to be introduced strictly in accordance with the actual proportion of their length to depth to main deck.

While the plating immediately above the main deck sheer strake in spar deck vessels is less in thickness than the plating below, and thus considerably less than what would be required for a three deck vessel between the main and upper decks, it is found to be necessary, in order to provide structural efficiency, to increase the thickness of the topmost strake of side plating (the spar deck sheer strake). Hence we find in Lloyd's Rules that both a width and thickness is specified for the spar deck sheer strake according to the 2nd numeral. In order to exemplify the difference in thickness of the side plating between the main and upper decks in a three deck and in a spar deck vessel, it is found on referring to Lloyd's Rules, where the former is 12, 13 and 14 twentieths in thickness, the latter need only be 9 twentieths.

While the foregoing are the principal features in the construction of ordinary spar deck vessels, it will now be evident that the smaller numerals will generally cause a reduction in the scantlings of the material throughout these vessels, as compared with three deck vessels of the same dimensions.

Second, Spar Deck Vessels in excess of Rule Requirements.—By carrying up all the reverse frames to the spar deck, and by introducing additional material in such localities as will undoubtedly increase the structural strength of the ship girder, concessions may be obtained in the matter of freeboard. Such additions to strength might be gradually made so as to ultimately bring the ordinary spar deck vessel through every stage of structural strength, until an equivalent in strength to the three deck vessel of full scantlings is produced, and naturally, corresponding allowances in freeboard would be secured; or, in other words, the vessel being now a three decker, a three deck freeboard would be assigned.

The freeboard for a spar deck vessel is measured downwards from the spar deck.

The standard height of a spar deck 'tween decks is 7 ft. Should this height be exceeded *or be less than the standard*, a modification must be made in the freeboard assigned.*

AWNING DECK VESSELS.

Structural Features.—In awning deck vessels, the main deck is the strength deck, it being assumed that damage to the erection above the main deck would not necessarily endanger the safety of the vessel.

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* In *spar decked* steam vessels requiring not more than one steel deck, the wood 'main deck' may be dispensed with, provided the beams, frames, and reversed frames be of the sizes required for three deck vessels, and all reversed frames be extended to the spar deck. A special freeboard may then be assigned.

However, although the awning deck erection is only a comparatively light superstructure erected on the main deck of the vessel, it affords both valuable reserve buoyancy as well as additional strength to the ship girder, and these are fully taken into account in the Freeboard Tables.

The freeboard for awning deck vessels is measured from the main deck downwards.

The 1st and 2nd numerals for awning decked vessels are obtained in the same manner, and are in every way identical with those of a spar decked vessel of the same dimensions to the main deck—the girth and depth being taken to the main deck.

Thus, the frame spacing, the size of frames, reverse frames, thickness of bulkheads, depth and thickness of floors, size of bar and flat plate keels, stem and stern posts, keelson and stringer angles, constructive material in double bottom, thickness of shell plating from keel up to and including the main deck sheer strake, main deck beams, hold beams, are all exactly of the same scantlings as for a spar decked vessel of similar dimensions up to the main deck, excepting that the addition for extreme proportions, as we shall see, will in all probability be somewhat more excessive than in the spar deck. Indeed, all the afore-mentioned scantlings are identical with what would have been required had the main deck been the upper deck, and the vessel, therefore, a simple two decker.

The beams for the awning deck are less in size than required for a spar deck of the same breadth. For example, under a steel spar deck 40 ft. in breadth, bulb angle beams $7 \times 3 \times \frac{9}{20}$ would be required upon every frame, while for an awning deck of similar breadth, bulb angles $6 \times 3 \times \frac{8}{20}$ would be sufficient.

The awning deck being simply a light superstructure, the sheer strake is placed at the main deck (the strength deck). The plating above the sheer strake is comparatively very light. For example, where in a three deck vessel whose plating below the sheer strake and between the middle and upper decks is required by rule to be $\frac{13}{20}$ths or $\frac{14}{20}$ths in thickness, and in a spar deck vessel $\frac{9}{20}$ths between the main and spar deck sheer strakes, $\frac{7}{20}$ths only is required by rule for an awning deck vessel.

The awning deck erection being of much less structural value than the structure of a spar deck vessel above the main deck, vessels of the former type are more dependent for structural strength upon the material up to the main deck, and in effect come to be of more extreme proportions than the spar deck, and vastly more so than the three deck vessel. This fact must therefore be taken into account and the main hull strengthened accordingly. This is provided for by taking the ratio of length to depth strictly as obtained, that is, exactly as though the vessel were of two deck type, the erection being entirely ignored. Thus, unlike the spar deck vessel, no reduction whatever is permitted in the proportions. Hence, more *additional* strength is introduced into an awning deck vessel than into either a spar or three deck vessel of similar external dimensions.

All bulkheads in awning deck vessels extend to the height of the main deck excepting the collision bulkhead, which should reach to the height of the awning deck. All the frames extend to the awning deck stringer plate. All the reverse frames extend to the top of the angle bar which runs continuously along the main deck stringer plate on the inside of the frames.

Awning deck vessels must have a complete main deck laid and caulked, and the coamings round all hatches should be built as though the main deck were the weather deck. The importance of this will be evident when the lightness of the superstructure above the main deck, and consequently its more damageable nature, is considered. To vessels having strength in excess of the awning deck requirements, but below the spar deck standard, a load line is determined in proportion to their structural strength as compared with a spar deck vessel.

The following Table will give some idea of the comparative scantlings of a three deck, a spar deck, and an awning deck vessel, as required by Lloyd's Rules.

COMPARISON OF CONSTRUCTION AND SCANTLINGS OF A THREE DECK, A SPAR DECK, AND AN AWNING DECK VESSEL, having Cellular Double Bottoms, each of the same Length (inside of Stem and Stern Posts), Moulded Breadth and Depth Moulded to Upper, Spar, and Awning Decks respectively, and Height of 'Tween Decks. 'Tween Decks, 7 ft. Length, 350 ft. Moulded Breadth, 46 ft. Depth from Top of Keel to Beam at Centre (with Normal Round up), 30 ft.

Three Deck Vessel.		Spar Deck Vessel.		Awning Deck Vessel.	
Length,	350 ft.	Length,	350 ft.	Length,	350 ft.
Breadth, moulded,	46 ,,	Breadth, moulded,	46 ,,	Breadth, moulded,	46 ,,
Depth ,, to upper deck,	30 ,,	Depth ,, to spar deck,	30 ,,	Depth ,, to awning deck,	30 ,,
		,, ,, to main deck,	23 ,,	,, ,, to main deck,	23 ,,
Half girth of midship frame,	48 ,,	Half girth of midship frame,	41 ,,	Half girth of midship frame,	41 ,,
,, moulded breadth,	23 ,,	,, moulded breadth,	23 ,,	,, moulded breadth,	23 ,,
Depth,	30 ,,	Depth,	23 ,,	Depth,	23 ,,
1st numeral,	94 ,,	1st numeral,	87 ,,	1st numeral,	87 ,,
2nd ,,	32900 ,,	2nd ,,	30450 ,,	2nd ,,	30450 ,,
Depths in length to upper deck,	11·6.	Depths in length, 13·2 to main deck (actually 15·2).		Depths in length, 15·2 to main deck.	
Frames, $5\frac{1}{2}\times3\frac{1}{2}\times\frac{9}{20}$, all to upper deck.		Frames, $5\frac{1}{2}\times3\frac{1}{2}\times\frac{8}{20}$, all to spar deck.		Frames, $5\frac{1}{2}\times3\frac{1}{2}\times\frac{8}{20}$, all to awning deck.	
Reverse frames, $4\times3\frac{1}{2}\times\frac{9}{20}$, to upper and middle deck alternately.		Reverse frames, $4\times3\frac{1}{2}\times\frac{8}{20}$, to spar and main decks alternately.		Reverse frames, $4\times3\frac{1}{2}\times\frac{8}{20}$, all to main deck.	
Frame spacing, 24 in.		Frame spacing, 24 in.		Frame spacing, 24 in.	
Or deep framing in lieu of hold beams, 9 in. deep.		*Or* deep framing in lieu of hold beams, $8\frac{1}{2}$ in. deep.		*Or* deep framing in lieu of hold beams, $8\frac{1}{2}$ in. deep.	
With side stringers, 23 in. wide.		With side stringers, 22 in. wide.		With side stringers, 22 in. wide.	
Bulkheads, lower half, $\frac{7}{20}$; upper, $\frac{6}{20}$.		Bulkheads, lower half, $\frac{7}{20}$; upper, $\frac{6}{20}$.		Bulkheads, lower, $\frac{7}{20}$; upper, $\frac{6}{20}$.	
Pillars (hold), $3\frac{3}{4}$ in. diameter.		Pillars (hold), $3\frac{5}{8}$ in. diameter.		Pillars (hold), $3\frac{5}{8}$ in. diameter.	
Stem bar, $11\times2\frac{7}{8}$.		Stem bar, $11\times2\frac{3}{4}$.		Stem bar, $11\times2\frac{3}{4}$.	
Flat plate keel, $36\times\frac{17}{20}$, to be doubled for half length amidships.		Flat plate keel, $36\times\frac{17}{20}$, to be doubled for half length amidships.		Flat plate keel, $36\times\frac{17}{20}$, to be doubled for half length amidships.	
Stern frame, $11\times6\frac{3}{4}$.		Stern frame, $11\times6\frac{1}{2}$.		Stern frame, $11\times6\frac{1}{2}$.	
Garboard strake, $36\times\frac{18}{20}$.		Garboard strake, $36\times\frac{18}{20}$.		Garboard Strake, $36\times\frac{18}{20}$.	
Upper deck sheer strake, $44\times\frac{15}{20}$.		Spar deck sheer strake, $40\times\frac{11}{20}$, doubling for whole width.		No extra thickness for shell at awning deck.	
Shell not increased in thickness at middle deck.		Main deck sheer strake, $44\times\frac{18}{20}$.		Main deck sheer strake, $44\times\frac{18}{20}$, with doubling for whole width.	

Garboard to sheer strake (upper deck), $\frac{12}{20}$, with an additional $\frac{1}{20}$ on three bilge strakes, and $\frac{2}{20}$ on strake below sheer strake.	Garboard to main deck sheer strake, $\frac{12}{20}$.	Garboard to main deck sheer strake, $\frac{13}{20}$, with doubling to strake below sheer strake.
	Shell plating between main and spar deck sheer strakes, $\frac{9}{20}$.	Shell plating above main deck, $\frac{7}{20}$.
Upper deck to be of steel, $\frac{7}{20}$ thick for whole length.	Spar deck, steel, $\frac{7}{20}$ thick for whole length.	Awning deck may be of wood.
Middle ,, ,, ,, half ,, amidships.	Main ,, ,, ,, ,,	Main deck, steel, $\frac{8}{20}$ thick for whole length.
......	......	Lower ,, ,, ,, ,,
Upper deck stringer plate, 55 × $\frac{10}{20}$.	Spar deck stringer plate, 54 × $\frac{11}{20}$.	Awning deck stringer plate, 44 × $\frac{9}{20}$.
Middle ,, ,, 55 × $\frac{10}{20}$.	Main ,, ,, 54 × $\frac{10}{20}$.	Main ,, ,, 55 × $\frac{10}{20}$, with doubling over midship length.
Lower ,, ,, 46 × $\frac{9}{20}$.	Lower ,, ,, 44 × $\frac{9}{20}$.	Lower deck stringer plate, 55 × $\frac{10}{20}$.
Upper deck beams, 8½ × 3 × $\frac{11}{20}$, bulb angles on every frame.	Spar deck beams, 8 × 3 × $\frac{10}{20}$, bulb angles on every frame.	Awning deck beams, 8½ × $\frac{8}{20}$, bulb, 3 × 3 × $\frac{7}{20}$ angles.
Middle deck beams, 8½ × 3 × $\frac{12}{20}$, bulb angles on every frame.	Main deck beams, 8½ × 3 × $\frac{12}{20}$, bulb angles on every frame.	Main deck beams, 8½ × 3 × $\frac{12}{20}$.
Lower deck beams, 11½ × $\frac{10}{20}$, bulb plate on alternate frames with two angles, 3½ × 3½ × $\frac{8}{20}$.	Lower deck beams, 11½ × $\frac{10}{20}$, bulb plate on alternate frames with two angles, 3½ × 3½ × $\frac{8}{20}$.	Lower ,, 11½ × $\frac{10}{20}$.
Bilge stringer, two angles, 6½ × 4½ × $\frac{9}{20}$, with $\frac{9}{20}$ intercostal plate for half length.	Bilge stringer, two angles, 6½ × 4½ × $\frac{9}{20}$, with bulb plate, 12 × $\frac{12}{20}$, and intercostal, $\frac{9}{20}$.	Bilge stringer, two angles, 6½ × 4½ × $\frac{9}{20}$, with bulb plate, 12 × $\frac{12}{20}$, and intercostal, $\frac{9}{20}$.
Side stringer, two angles, 6½ × 4½ × $\frac{9}{20}$, with $\frac{9}{20}$ intercostal plate for half length.	Same as Three Deck.	Same as Three Deck.
Centre through plate, 42 × $\frac{10}{20}$.	,, ,,	,, ,,
Two side girders, $\frac{8}{20}$.	,, ,,	,, ,,
Floors on every frame, $\frac{8}{20}$.	,, ,,	,, ,,
Tank margin plate, 28 × $\frac{8}{20}$.	,, ,,	,, ,,
,, top centre strake, $\frac{14}{20}$; in engine and boiler space, $\frac{10}{20}$; in holds, $\frac{8-7}{20}$.	,, ,,	,, ,,
Centre girder top angles, 4 × 4 × $\frac{9}{20}$.	,, ,,	,, ,,
Keel plate angles, 6½ × 4½ × $\frac{9}{20}$.	,, ,,	,, ,,

Note.—The foregoing scantlings are for steel material extending over the half length amidships. Towards the ends, considerable reduction takes place in the sectional area of both plates and bars.

MODIFICATIONS OF PRINCIPAL TYPES.

Raised Quarter Deck Vessels.—See figs. 47 and 50. A considerable difference exists between an erection called a raised quarter deck, and such erections as complete or partial awning decks, poops, bridges, and forecastles. Indeed, in the truest sense, a raised quarter deck is not an erection, but a *bona-fide* integral part of the ship's hull—the term 'erection' being used for purposes of convenience. The raised quarter deck is in reality an increase in the depth of the vessel over part of her length—usually the after portion of length. (See figs. 47 and 50.) The height of a raised quarter deck above the main deck seldom exceeds 4 ft., though it is often of less height. It will scarcely be necessary to say that the raised quarter deck erection is *always* an extension in the depth of the hull of the vessel immediately above the *main* deck, and is never found above spar or awning decks, where it would be practically useless. So valuable is the increased buoyancy of the space provided by a raised quarter deck 4 ft. in height, that it receives as much credit in the assignment of the freeboard as would be given to a long poop erection of similar length and substantially closed with a bulkhead at the fore-end, and of at least 7 ft. in height.†

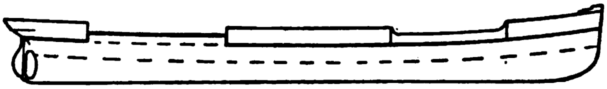

FIG. 50.*—Raised Quarter Deck Vessel.

While it is customary to speak of the raised quarter deck being of a certain height above the main deck, it must be clearly understood that neither decks nor beams are fitted to the main deck immediately under the raised quarter deck excepting for a short distance (a few frame spaces) at the termination of the raised quarter deck or 'break,' as it is usually termed. What is really done is to interrupt the continuity of the main deck by lifting it up for part of its length to a certain height, and then term the raised part, a raised quarter deck. It is therefore constructed exactly as though it were the main deck carried continuously all fore and aft.

The more detail work of obtaining an efficient connection between the main and raised quarter decks is dealt with a little later in this volume (see page 123). It is customary to adopt raised quarter decks in one and two deck vessels—seldom in three deck vessels, and it may safely be said never when two laid decks are absolutely required. Perhaps the principal reason which led to the wide adoption of the raised quarter deck type of vessel may be given as follows:—

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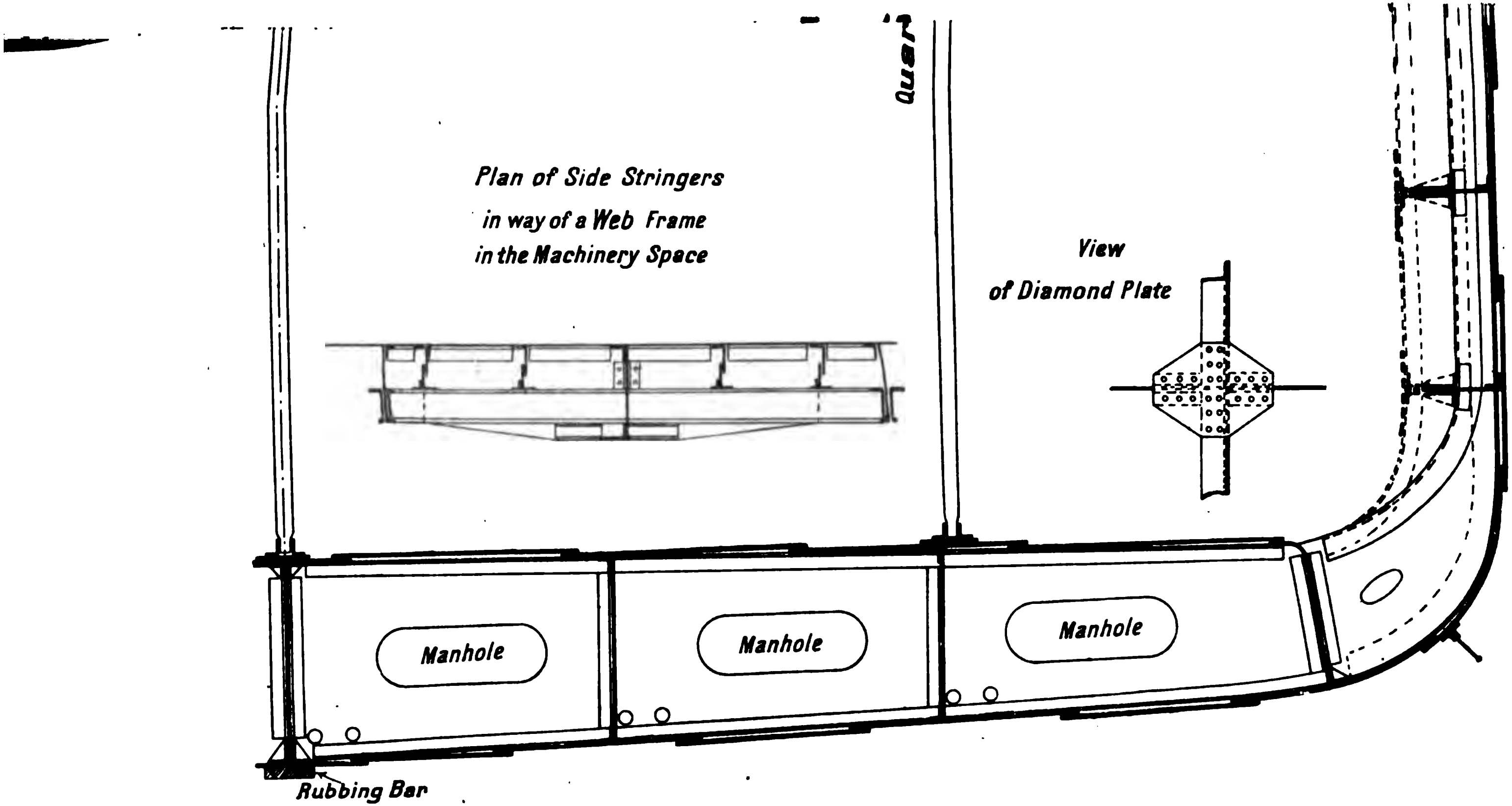
* The heavy black lines in figs. 50 to 55 divide the hull proper from the erections.

† When the raised quarter deck is of less than 4 ft. in height above the main deck, the allowance for freeboard suffers reduction.


Quar
Plan of Side Stringers
in way of a Web Frame
in the Machinery Space
View
of Diamond Plate
Manhole
Manhole
Manhole
Rubbing Bar

In comparatively small vessels—say up to about 250 ft. in length—it was found that when the engines and boilers were placed amidships, so much hold capacity was lost owing to the space occupied by the shaft tunnel, in combination with the fact that most cargo vessels are designed with the after body somewhat finer than the fore body in order to get a form as consistent with speed requirements as possible, that when laden with homogeneous cargo, to bring such vessels to a satisfactory trim was practically impossible—the tendency being to trim by the head. By increasing the depth of the hold space abaft of the engines by raising the main deck (constructing a raised quarter deck), this objectionable feature was obviated. Thus, a vessel with a raised quarter deck represents in some degree parts of two separate vessels united into one. The structure of that part without the raised quarter deck is in strict accordance with what would be required for a vessel of the same depth throughout to the main deck. In way of the raised quarter deck, however, all the frames extend to the raised quarter deck stringer plate. The alternate reverse frames extend to the same height, while the intermediate reverse bars are carried to a height such as would be required for a vessel whose 1st numeral was computed by the depth and half girth being taken to the raised quarter deck. The construction of the raised quarter deck, as we have already stated, is a continuation of the main deck. While the number and arrangement of hold beams, beam stringers, and stringers in hold in that part of the vessel uncovered by the raised quarter deck is in accordance with the requirements for the depth taken to the main deck, in the after part of the vessel, which comes in way of the raised quarter deck, these structural items are regulated by the depth, which is now increased by the height of the raised quarter deck above the main deck. It will now be seen that the disposition of the stringers below the raised quarter deck may differ considerably from that in the other part of the vessel. Indeed, it is possible that the depth, which has now been increased by the height of the raised quarter deck above the main deck, may have actually produced the necessity for an additional tier of beams, or at any rate, additional side stringers. These, of course, must be fitted, unless in the event of an additional tier of hold beams being required, compensation in the form of deep framing, or web frames, be fitted in lieu thereof.

Now we have previously seen how highly important it is that the continuity of all structural strength should be rigorously maintained. Hence, in vessels of this type, great attention must be bestowed upon the union of that part of the vessel covered by the raised quarter deck and the fore length. This is effected by overlapping the main and raised quarter decks for 2, 3, 4, or 5 frame spaces according to the size of the 2nd numeral and the proportions of the vessel; while in the case of the side stringers these also are overlapped, or, in some instances, scarphed into one another. The overlapping lengths of the main and raised quarter decks are further blended together by means of a number of fore and aft webs of plating called diaphragm plates.*

In these vessels, the main deck sheer strake is usually carried continuously right aft to the stern, while the side plating above the sheer strake and in way of the raised quarter deck may be $\frac{1}{20}$th of an inch less in thickness than the shell plating below, if such is $\frac{7}{20}$ths of an inch in thickness or more.

As the stresses produced by longitudinal bending moments are always severest wherever any sudden diminution or increase takes place in longitudinal strength, it is very important that special strengthening be introduced at the break, so as to blend, as it were, the strength of the raised quarter deck with its increased depth into the other length of the vessel. Hence it is usual to double part of the topside plating for a reasonable distance before and abaft of the 'break.' This doubling is usually fitted to the sheer strake, or when the vessel has a bridge house connected to the raised quarter deck the better method is to double the side plating of the raised quarter deck for a similar distance. In any case, the raised quarter deck side plating must be strengthened in way of the break, and thus, if it is not doubled, it must be increased in thickness, in addition, of course, to the doubling of the sheer strake.

The thickness of the bulwark plating should be increased at the ends of such erections, thus further tending to blend the strength of the one part into that of the other. Great care must be exercised in arranging the butts of the side plating and stringers in way of the break, and ample strength should be introduced into the butt connections whether they be strapped or overlapped. Usually all the butts are treble riveted in the principal structural parts in way of the break, and the thickness of butt straps increased.

As the break bulkhead is a most vital part in the structure, it is essential that it be of satisfactory thickness (usually same as bridge side plating), well constructed, and connected and stiffened. To this bulkhead the raised quarter deck should be connected by means of double angles.†

Though distinguished by the name 'raised quarter deck' vessel, this type belongs to the 'full scantling' class, no such erection as a raised quarter deck ever being built, as has already been stated, upon spar or awning deck vessels. They must therefore be considered upon this understanding.

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* The length of these diaphragm plates is equal to the length of the overlap of the raised quarter deck over the main deck, and the width to the distance between the overlapping decks. The diaphragm plates should be well connected to these two decks by double angles. For such a vessel as illustrated in fig. 47 about four diaphragm plates would be required.

† In order to obtain the *minimum* freeboard for well-deck vessels, it is necessary :—

1. When the crew is berthed in the forecastle, that the 'well' between the bridge and the forecastle be bridged by a gangway supported on stanchions (which may be made portable if desired) so as to facilitate the passage of the sailors and firemen to their respective quarters. Where, however, the well is 80 feet or more in length, or the vessel is under 150 feet in length, the gangway just referred to is not required.

Maximum Stress.—Now what is a severe stress for the material in a vessel of the spar or awning deck type is also a severe stress for one of full scantlings. The idea must not be entertained that because these types differ in their adaptation or efficiency for carrying deadweight, that there is any varying degree of maximum stress to which they are respectively capable of being subject, when fully and properly loaded to their properly assigned load lines. Such an idea is erroneous. That is not the manner in which ships are designed and classified. Indeed, the absurdity of such an idea must be obvious after very little thought. The only intelligent and scientific method which can be adopted in considering the deadweight carrying capacity of any vessel is to assign to her such a draught that when fully loaded with a homogeneous cargo, the material in the structure subject to the greatest stresses—tensional, tortional, and compressive—will be able to endure the same without the possibility of rupture or distortion occurring, and also with no possibility of the material situated in any intermediate locality between the regions of maximum stresses collapsing.

Thus, assuming that a three deck, a spar deck, and an awning deck vessel were built to Rule Scantlings, and it were desired that when each was fully loaded with a homogeneous cargo, not more than 7 tons stress per square inch of material should be experienced on the top of the upper deck sheer strake, it would follow, after the comparison we have made of the scantlings of these respective vessels (see table on p. 120) that the spar deck vessel must have more freeboard than the three deck type, and the awning deck more again than the spar deck type, simply because the structural material is less in midship sectional area in the spar than in the three deck vessel, and less in the awning than in the spar deck type. And with less sectional area of material in the midship sections of vessels of similar depth and breadth, and disposed according to the usual practice for these respective types, the moment of inertia must be less in the spar deck type, and least in the awning deck type as compared with the three deck type. And less moment of inertia with equal bending moments must produce greater stress. But this must be obviated of absolute necessity. Hence

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2. That the engine and boiler openings be protected and entirely covered by an efficient bridge house.

3. That the total area of the freeing ports in the bulwarks in the well be sufficient to speedily rid the deck of water. This area is determined by the Board of Trade according to the length of the well.

4. That in well deck vessels of the highest class having erections extending over $\frac{7}{10}$ths of their length, the bridge front bulkheads must be specially strengthened and the hatch coamings at least 30 in. high above the deck, while in order to facilitate the means of getting rid of seas shipped into the well, the freeing port area must be 25 per cent. in excess of that referred to in the foregoing paragraph (3).

smaller bending moment is obtained by carrying smaller deadweight, which means less draught or more freeboard. Hence the varying draughts of three deck, spar deck, and awning deck vessels.

However the design of a vessel may be altered, or whatever peculiarities may be introduced into her construction, she must finally, in receiving her statutory freeboard, come under such test as we have just described, and must satisfy that with a fully loaded homogeneous cargo of a certain density, she is not unduly stressed, and that she possesses at least the minimum percentage of reserve buoyancy required by the Load Line Act, 1890.

However, as we have shown in Chapter V., there is no such thing as a standard maximum stress for all types and sizes of vessels; for local requirements, especially as seen in small vessels, may demand certain structural strength in order to resist strains apart altogether from those produced by longitudinal bending moments. Hence small vessels, when fully loaded, are rarely stressed beyond 4 or 5 tons per square inch, while large vessels may reach as much as 8 tons and over.

In the Freeboard Tables and Rules fixed by Act of Parliament, and from which all assignments for British Load Line Certificates are made, the three types of vessels we have thus far considered—'full scantling,' 'spar deck,' and 'awning deck'—are all that are mentioned for steam vessels. So that to what society's rules a vessel may be constructed and classified, or to what special design she may be built matters not. If she is required to have the minimum freeboard, she must belong, from a structural strength point of view, to one of these three types, or to some modification or intermediate grade between them, and upon the strength so ascertained will she receive her statutory freeboard.

Deck Erections other than Awning and Raised Quarter Decks.—Having noted the value of the complete awning deck erection from both a buoyancy and a structural strength point of view, and also the raised quarter deck, which, it may not be unwise to reiterate, is much more than an erection, or it may be still more correct to say that it is not an erection at all, but an integral and vital part of the vessel's hull, we shall briefly examine the structural features and value of other erections which rank of less importance. Vessels having such erections may be described and illustrated as follows:—

1. *Partial Awning Deck Vessels.*—With long raised quarter deck and partial awning deck covering the whole length. See fig. 51.

After the description already given for raised quarter deck and awning deck vessels, little more needs to be said about this type. Such vessels are built to scantlings from numerals obtained by taking the girth and depth up to the main deck, the erections agreeing with the rule requirements for raised quarter decks and awning decks respectively. The part awning deck erection, which, as has been shown, is of comparatively light construction, is well suited for light cargo, such as cattle or even passengers.

It affords protection to the engine and boiler casings, and forms, with the raised quarter deck, a continuous erection providing valuable reserve buoyancy, for which due allowance is made in determining the freeboard. The main and raised quarter decks are scarphed (overlapped) as for vessels with raised quarter decks unconnected to bridges or part awning decks, except in the very smallest vessels, where a system of knee bracketing is sufficient.*

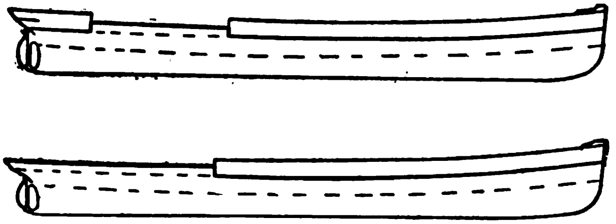

FIG. 51.—Vessel having long raised Quarter Deck and partial Awning Deck together completely covering the whole length (with or without a poop). Known as partial Awning Deckers.

2. *Shelter Decked Vessels.*—See fig. 52.

The great development which has taken place in recent years in the cattle carrying trade is chiefly responsible for the evolution of the 'shelter deck' vessel. This is usually a three deck vessel with a complete erection all fore and aft, entirely closed from the sea, with the exception that it is fitted with one or more openings through the shelter deck, which may extend from side to side of the deck, or simply be an opening resembling

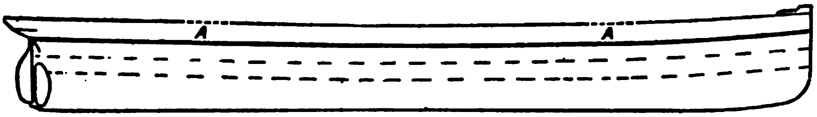

FIG. 52.—Shelter Decked Vessel.

Note.—Dotted lines in Shelter Deck at A denote openings (not hatchways).

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* It may be pointed out that the Board of Trade Freeboard Rules allow even a less freeboard in vessels of this type than for plain rule awning deck vessels if certain structural conditions are fulfilled whereby the partial awning deck erection is brought up to a state of structural efficiency more in harmony with the strength of the raised quarter deck. It is also assumed that the partial awning deck covers the engine and boiler openings. These structural conditions, the rules state, must be in accordance with the requirements described in section 44 of Lloyd's Rules for the year 1889, and include increased thickness of side plating, stronger stringer plates, a steel or iron deck, and increased riveting in the side plating. Where, however, the partial awning deck is built to the ordinary rule requirements for awning deck vessels, the allowance for freeboard will be similar to that for a vessel with a complete awning deck.

a hatchway, excepting that no coamings are fitted, and no permanent means provided for battening down the opening with planks. With such a deck opening or openings, it is evident that, in heavy weather, it is not improbable that in shipping seas on deck, water may find its way into the 'tween decks between the upper and the shelter decks. Hence, waterports and scuppers are fitted in shelter deck spaces.

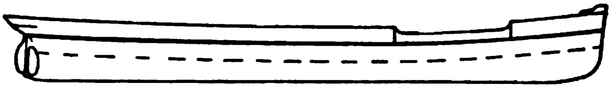


FIG. 53.—Well Deck Vessel, *first type*, long poop and bridge combined, and topgallant forecastle.

Well Deck Vessel of second type is that previously described and illustrated in figs. 47 *and* 50.

A principal reason why this type of erection is generally adopted for the carrying of cattle is that all unenclosed space in a shelter deck 'tween decks is exempted from the gross tonnage of the vessel, while according to its value in affording reserve buoyancy and strength to the ship as a whole, it receives consideration in the assignment of the freeboard.

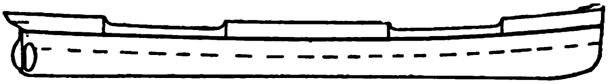


FIG. 54.—Vessel with poop, bridgehouse, and forecastle.

There are no definite rules for the construction of shelter deck erections But, with the exception that the shelter deck is an erection upon a *three deck* vessel (in arriving at whose first numeral a deduction of 7 is made, while no such deduction is made for the awning deck numeral), it is very similar in construction to an awning deck erection. Often the shelter deck is of steel.

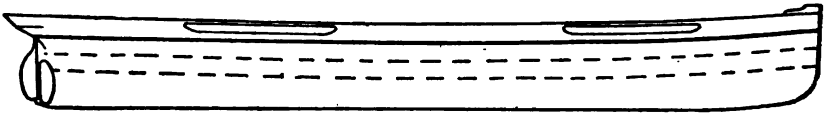


FIG. 55.—Shade Deck Vessel.

Against its value from a strength standpoint there is to be considered the diminished value of the buoyancy of such 'tween decks owing to the openings already mentioned. By fitting complete iron or steel bulkheads to the poop, bridge, and forecastle spaces in the shelter deck 'tween decks, its value as an erection is considerably enhanced.

Well Deck Vessels.—With long poop and bridge combined, and topgallant forecastle. See fig. 53.

The particulars of the principal structural features of such erections may be enumerated as follows:—

(1) All frames extend to poop, bridge, and forecastle decks.

(2) Poop and bridge beams of same size as awning deck beams.

(3) Forecastle beams similar to spar deck beams.

(4) Side plating of same thickness as required for awning deck vessels.

(5) As the forecastle sides are particularly exposed to the full force of the sea, extra stiffness to the plating should be introduced, especially in large vessels. This may be done by carrying up the alternate reverse frames, or by fitting a double angle stringer midway between the forecastle and upper deck.

(6) The bulkhead at the fore end of the combined poop and bridge house should be of same thickness as the side plating—the coamings being $\frac{1}{20}$th of an inch thicker. This bulkhead should be well stiffened with bulb plates and angles or channel bars or any other equivalent, spaced about 30 in. apart. These bulb stiffeners should be thoroughly connected to the coaming plates and the decks between which the bulkhead extends. If these decks are not plated, athwart-ship plates should be fitted to their beams, so that an efficient connection by means of bracket knee plates may be effected. (See fig. 56.)

The importance of this will be evident when it is remembered that the well between the forecastle and the bridge is specially subject to the incursions of heavy seas, which often dash furiously against the bridge front bulkhead, damage to which might seriously endanger the safety of the vessel should water find its way into the deck openings over the engines and boilers, which are enclosed by comparatively light casings.

(7) We have previously drawn attention especially to the necessity of considerable additions to the strength of the topsides in the way of the main deck in awning deck vessels of extreme proportions, that is, over eleven depths to length. The same necessity for additional strength exists where a considerable proportion of the length of a vessel ($\frac{3}{8}$ths or over) is covered by erections. Thus, in well deck vessels of this type, whenever either of these conditions exist, strength to the topsides over the middle half length of the vessel should be introduced either by doubling the sheer strake or increasing the thickness of the bridge side plating and stringer plates, and the efficiency of the butt connections of these parts. In any case, the sheer strake should be doubled for about 20 ft. at the fore end of the bridge, and the raised quarter deck side plating at the break for a similar distance.

Vessel with Poop, Bridge, and Forecastle.—See fig. 54. All the frames extend to the height of the stringer plate on the deck of each of these erections. In neither the poop nor the bridge is it necessary to carry any reverse frames above the upper deck, unless the 'tween deck height of such erections be unusually great, when additional support would necessarily be required. In the case of the forecastle, whose sides are exposed to the full force of head seas, the necessity for ample strength and stiffening is evident. This can be obtained by extending the alternate reverse frames to the forecastle deck, or by fitting a double angle or tee bar stringer along the inside of the frames midway between the two decks. When these stringers meet at the stem bar, they should be connected by means of a plate bracket or breast hook.

While the side plating of poops, bridges, and forecastles is usually comparatively thin, it may be advantageous in certain cases to increase the thickness of the forecastle side plating for the reason just given

A stringer plate is fitted to the ends of the beams on each of these erections.

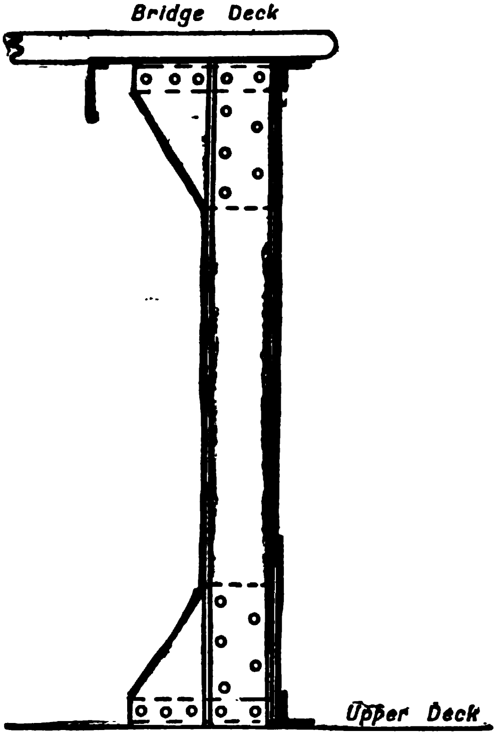


FIG. 56.—Bridge front Bulkhead stiffened with Channel Bars.

In determining the load line for vessels of this kind, an allowance is made for the erections strictly in accordance with the value of the buoyancy which they afford. Thus, if the bridge be closed with a thoroughly efficient watertight bulkhead at each end, and the poop with a bulkhead at its fore end, the allowance will naturally be more than would have been made had these spaces been open at the ends or pierced by alleyways or other permanent openings. The bridge front particularly should have a good coaming plate well connected to the deck, and the stiffeners should be at least as large as the main frames, spaced about 30 in. apart, with bracket connections to the decks at their upper and lower extremities.

Shade Deck Vessels.—The principal function of a shade deck is to afford a shelter and provide a promenade for passengers. As the sides are open, the 'tween-deck space affords no buoyancy, and as the construction is usually of a very light character, because of the light duty it has to perform in the economy of the ship structure, it is practically valueless in contributing to the general structural strength of the vessel. It should, however, be sufficiently strong for the purpose for which it is erected, so as in no way to endanger the lives of the passengers or crew. Such decks may be constructed in a variety of ways; frame angles, tee bars, or round iron stanchions may be used to carry the shade deck beams, while the shade deck itself may be built of light beams with light stringer and tie plates upon which the wood deck is laid (see fig. 55).

Steel Sailing Ships.—Owing to the severity of the transverse stresses experienced by sailing ships, tending to rack and distort the form in that direction, additional transverse strength is introduced into large vessels (1) by carrying the reversed frames up to the gunwale on every frame, (2) by making the beams deeper than would be required for steam vessels of the same size, at any rate to the lower and orlop decks. Special care should be taken in the formation of the beam knees. When the knees are not made of bracket plates, the beam ends should be turned down to form the knees as shown in fig. 111. All beam knees should be three times the depth of the beam. (3) When no steel deck is fitted, there should be, in addition to the fore and aft tie plates, diagonal tie plates laid upon the deck, so as to effectively transmit the severe stresses from the masts and the adjacent beams to the stringer plates.

SECTION II.

Description and Illustration of the Principal Structural Features of some noted, and also some novel Types of Vessels—'Campania' and 'Lucania'—'Great Eastern'—Turret Steamers (Doxford's)—Trunk Steamers (Ropner's)—Self Trimming Steamers (Priestman's)—Some advances in Modern Shipbuilding—Steamers for carrying Oil in bulk—Water-ballast Arrangements.

'CAMPANIA' AND 'LUCANIA' (see figs. 57 and 58).

In these magnificent twin screw Transatlantic passenger steamers, we have an example of two of the finest specimens of naval architecture afloat. They belong to the Cunard Line, sailing regularly between Liverpool and New York, and were built in 1893, by the Fairfield Shipbuilding and Engineering Co. Ltd., Glasgow. Particulars of their principal dimensions, etc., are as follows:—

Length over all,	622' 6"
„ between perpendiculars,	600' 0"
Breadth extreme,	65' 3"
Depth moulded to upper deck,	41' 10"
„ to boat deck,	59' 6"

About 14 depths in length.

Engines—Twin Screw. Ten cylinders.

4 high-pressure cylinders,	37 in. diam.
2 intermediate „	79 „
4 low pressure „	98 „
Stroke	69 „

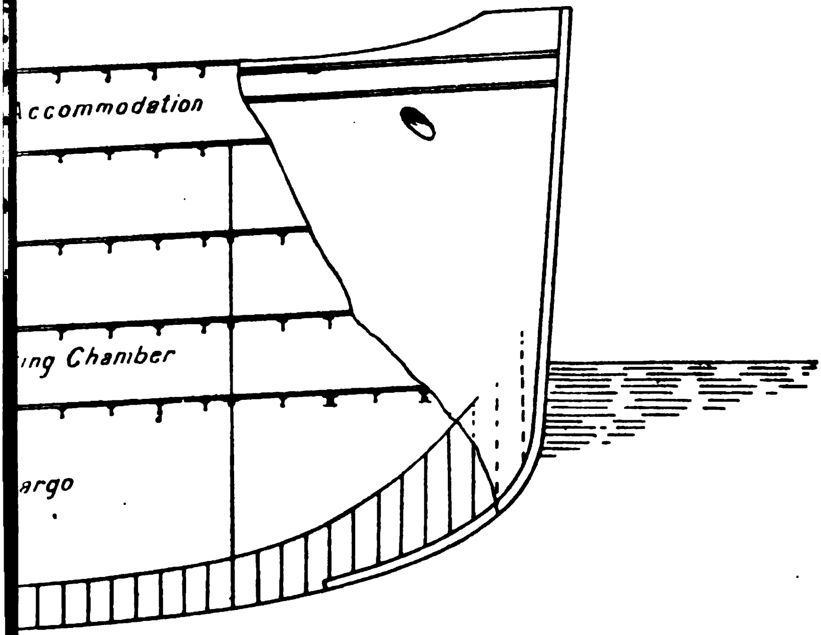
Boilers—12 double ended, 17' 6" diameter × 18' 9" long.
1 single „ „ „ „ 10' 9" „
1 donkey boiler, 11' „ „ 9' 3" „

Natural Draught.

Total number of furnaces, 102.
Working steam pressure, 165 lbs. per square inch.
Indicated horse power on trial, 31,000.
Speed on trial, 23·18 knots.
Average speed per hour on fastest passage, 22·01 knots.
Gross tonnage = 12,950 tons. Nett register tonnage, 4973.

Passenger accommodation—

First Class, 600.	Third Class, 1000.
Second Class, 400.	Crew, 450.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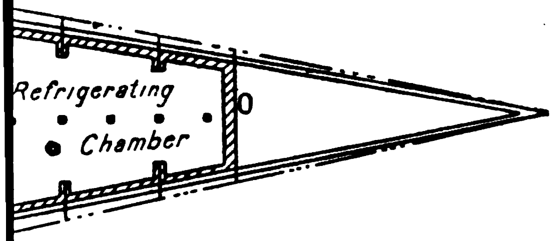
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Most of the structural features are distinctly shown in diagrams 57 and 58, which have been kindly furnished for this work by the Owners; hence, more than briefly drawing attention to the chief items in the construction is unnecessary.

The vessels are classed 100 A1 at Lloyd's. They fully comply with the rules of the Bulkhead Committee, in being subdivided into watertight compartments by transverse watertight bulkheads, in such a manner that any two (and in some cases, even three) of these compartments may be flooded without endangering the safety of the vessel. The bulkheads are spaced more closely towards the ends of the vessel where loss of buoyancy would cause most change of trim, and where the danger from collision is greatest. The bulkheads are stiffened by deep channel bars, and connected to the tank top and decks by bracket plates. Where passage-ways are required through these bulkheads, watertight doors are fitted, but these are of the least possible number.

Unlike some large passenger steamers, no central longitudinal bulkhead is fitted, excepting through the engine room. Longitudinal bulkheads, apart from structural strength, may be a source of danger to a vessel under some circumstances, for in the event of the shell being perforated and the sea finding access, the loss of buoyancy on the one side only may cause the vessel to take a very considerable list. The necessity for the longitudinal bulkhead through the engine room, however, is so apparent as to need little comment. The two engines driving the two propellers are kept in separate watertight compartments, and thus, in the event of one of them being flooded, the other remains intact, and the vessel has the advantage of propulsion by means of one propeller, at any rate.

The 'Campania' and 'Lucania' are on the Admiralty list of mercantile armed cruisers, and hence satisfy all requirements for such. Among other features, the boiler compartments are protected against shot at the sides and over the top by watertight coal bunkers. A cellular double bottom extends continuously throughout the whole length. The keel is of the flat plate type, 60 in. broad by over an inch in thickness (see midship section, fig. 58). It has a doubling on the inside of over $\frac{7}{8}$ths of an inch in thickness. The double bottom is about 56 in. in depth, excepting under the engines, where it is increased in depth to about 7 ft. 6 in., in order to form the engine seating. The centre through-plate is continuous all fore and aft with double angles at top and bottom. Between the centre through-plate and the tank margin plate, there is a *continuous* longitudinal girder, also with double angles at the top and bottom. Between this last mentioned continuous girder and the centre through-plate, and also between the same girder and the margin plate, intercostal girders are fitted as shown in fig. 58. Under the engines, however, where much greater strength and rigidity is required owing to the enormous power of the engines, two continuous and three intercostal girders are fitted on each side as shown in the section of the machinery space, fig. 58. The frames are of channel bar section, spaced 30 in. apart.

In order to give increased stiffness to the transverse framing, there are introduced at intervals, in addition to the numerous transverse bulkheads, deep web frames or partial bulkheads. These web frames are spaced more closely together in the engine and boiler space, where special precautions are obviously necessary.

There are four complete steel decks laid throughout the entire length of the ship, viz.:—Promenade deck, upper deck, main deck, and lower deck, all of which are wood sheathed. The boat and orlop decks have wide stringer and tie plates, and are laid with wood decks. The beams to all the decks are of the butterly tee bulb section, with the exception of those at the ends of the promenade deck, which are bulb angle. The promenade deck amidships is supported on T section steel stanchions, which are brought down to the sheer strake, and form stiffeners for the bulwarks (see midship section, fig. 58).

The frames extend continuously from the tank margin plate to the upper deck. The centre through-plate and tank margin plate and some of the side girders being continuous fore and aft, the floors must be intercostal between these longitudinals. At the fore end, where, on account of the high speed, severe panting stresses are encountered, the frames are doubled for a considerable distance abaft of the stem. Doublings are also fitted to the frames for a considerable distance forward of the stern post, where great stiffness is required to carry the propeller brackets through which severe strain is transmitted, especially when the vessel travels at a high speed. Double angle bar frames are fitted to all watertight bulkheads.

In all steam vessels, owing to interruptions in transverse strength caused by the omission and cutting of beams in the machinery space, too much attention cannot be given to the matter of compensation for such weakening of the structure, and to so strengthening this locality that no signs of weakness may be developed, and vibration reduced to a minimum. It is also necessary to ensure that the foundation upon which the engines and boilers rest is of the most substantial character. In such vessels as the 'Campania' and 'Lucania,' with their enormous engines developing 30,000 indicated horse power, the strengthening of the machinery space naturally became one of the most important subjects in the construction of these vessels.

As we have stated, the floors under the engines were increased considerably in depth, and additional longitudinal girders were introduced.

The section through the engine space (fig. 58) well illustrates this. In order that the various parts might be connected in the most efficient manner, all rivet holes in the structure under the engines were rimed and made perfectly true, and the angles in the double bottom were welded and joggled, so as to thoroughly combine the whole and make the transverse framing as continuous as possible.

As the orlop beams had necessarily to be dispensed with in the machinery space, compensation was provided by a semi-box stringer (see section, fig. 58), which is itself furthermore strengthened by the introduction of diaphragm plates at intervals.

The stringer plates on beams are connected to the shell by double intercostal angles instead of by a single angle as commonly adopted.

The shell plating is arranged on the overlap system from the keel to the under side of the main deck sheer strake.

The butts of the upper and main deck sheer strakes, and the strake of shell plating between, are connected by double butt straps quadruple riveted over the middle length and treble riveted at the ends. The straps are placed one inside, and one out. All the other shell butts are overlapped and quadruple riveted over the midship length, and treble riveted before and abaft this. As shown in the section, fig. 58, the upper deck sheer strake and the strake below are doubled over the middle length of the vessel. In long vessels it is a common practice to double one or more strakes of bilge plating, but in the case of the 'Campania' and 'Lucania,' increased strength was obtained by increasing the thickness of the bilge strakes, and adopting treble riveting at the edges or seams of these strakes.

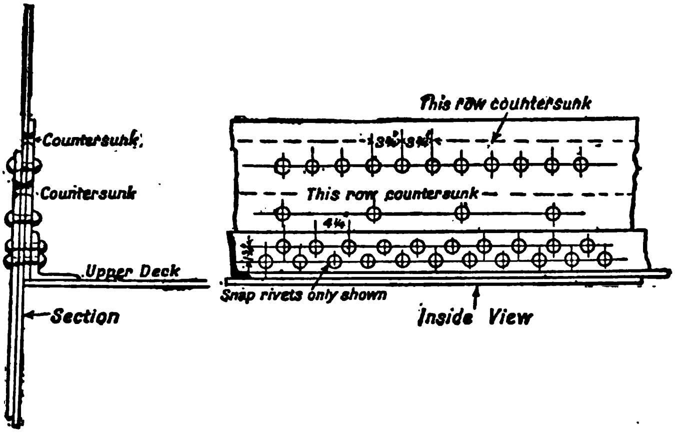

FIG. 58A.—Detail of Hydraulic Riveting in Upper Deck Sheer Strake.

In order to obtain the fullest efficiency, and to ensure the soundest workmanship, hand riveting was dispensed with in the connection of the upper deck sheer strake to the deck stringer plate, as it was practically impossible to obtain satisfactory workmanship by hand riveting so many plates of great thickness. (See fig. 58A.)

Hydraulic riveting was therefore adopted, and, as a consequence, the rivets are snap-headed. Though the exposed heads of such rivets may be considered by some to detract a little from the general appearance, this consideration was outweighed by the vastly improved character of the work, and the satisfaction felt in having the various thicknesses of plating thoroughly closed up. All rivets are of steel, and in way of the double bottom, the riveting is all done by hydraulic machinery. The shell plates range from ¾ in. to 1 in. in thickness.

The deck houses are of the composite type, having steel coamings, and frames, and beams (see fig. 169).

The upper deck is sheathed with teak, and the others with yellow pine. The stern frames and propeller brackets are of cast steel.

By adopting the system of bossing the frames at the after end (see figs. 157, 158), not only is thorough support given to the propeller shafts, but ready means of access is obtained to the shafts and their bearings throughout the whole length excepting the tail shafts.

When the ships were built, they were fitted with plate rudders having specially designed arms on either side. The plates for the rudders were made by Messrs. Krupp, of Essen, in Germany, and measured 22′ 0″ × 11′ 6″ × 1¼″ thick. The necessity of going abroad for these plates was afterwards called in question by British makers, and the matter was severely commented upon at the time by some of the leading journals. However, after the ships had run a few voyages, the plates were found to be cracked, and the owners refitted the ships with new cast-steel rudders made up in three sections.

'GREAT EASTERN'

(See figs. 59 and 60).

While the 'Campania' and 'Lucania' are two of the largest vessels afloat, their size was considerably exceeded by Scott Russell's great work, the famous 'Great Eastern,' and a few particulars about this vessel, together with the profile and midship section, figs. 59 and 60, will doubtless be interesting, if not instructive, for comparison.*

The 'Great Eastern' was 692 ft. in length over all.

Length between the perpendiculars, 680 ft.

Breadth moulded, 82 ft. 2 in.

Depth moulded to upper deck, 58 ft. 0 in.

Depths in length, about 11½.

This vessel was propelled by a screw propeller, and also by a pair of paddle-wheels. The total indicated horse-power was about 8000, the screw-engines being somewhat more powerful than the paddle, indicating about 4500 horse-power.

The maximum speed obtained was from 14 to 14½ knots per hour. There were ten tubular rectangular boilers 18 ft. long, 17 ft. 6 in. wide, and

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* The 'Great Eastern' has, however, since been exceeded in size by the White Star steamer 'Oceanic,' built by Messrs. Harland & Woolf.

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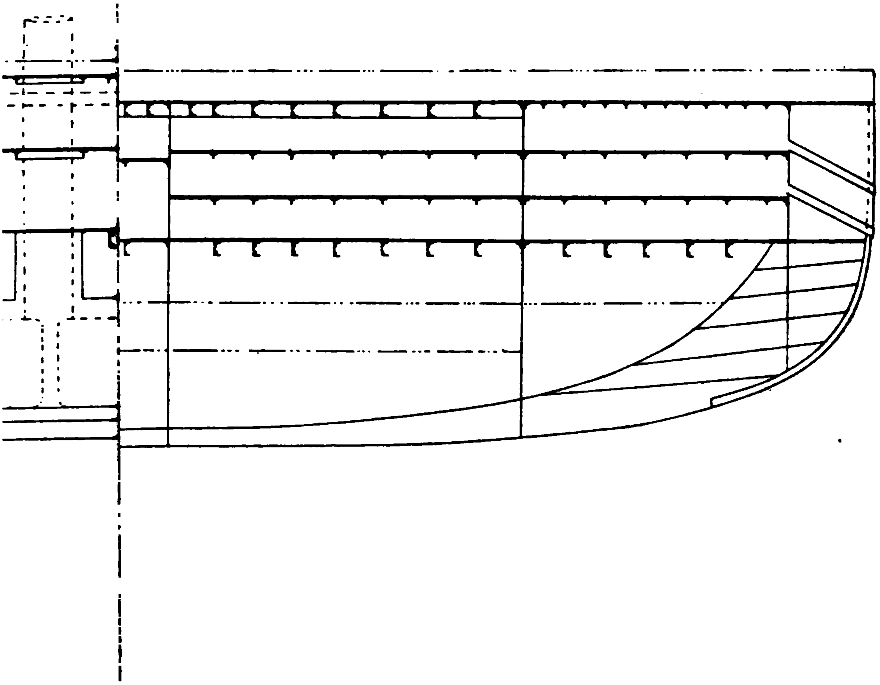


14 ft. high, with 112 furnaces in all, and a working steam-pressure of about 20 lbs.

Each set of engines had four cylinders with a diameter and stroke of 7 ft. and 4 ft. respectively in the screw-engines, and 6 ft. 2 in. and 14 ft. respectively in the paddle engines.

The propeller had 4 blades with a diameter of 24 ft. with 44 ft. pitch. The paddle-wheels were about 56 ft. in diameter. The vessel was designed to carry about 800 first class, 2000 second class, and 1200 third class passengers. It has sometimes been stated that the 'Great Eastern' was a huge failure. If being far ahead of the times constitutes a failure, she was one. Certainly she was never profitable commercially, but she was an advance in naval architecture such as has never been equalled since, and her designer (Brunel) must ever rank as one of the ablest and most ingenious naval architects that ever lived.

The fact is apparently often overlooked, that the experience provided by the 'Great Eastern' has directly, or indirectly, been of immense value to modern naval architects, and in no small way has contributed to the success of our largest ocean liners.

The system of her construction was unique, and although it has not been rigidly followed in the building of succeeding mercantile vessels, yet it has doubtless influenced the construction of ships generally.

She was built exclusively upon a system of longitudinal framing which was composed of plate girders spaced about 30 in. apart from the keel to the lower turn of the bilge, and from thence to the lowest deck at about twice this distance. (See fig. 60.)

These girders were entirely covered with an inner skin of watertight plating in addition to the outer shell. Such an arrangement not only added immensely to the strength, but contributed in a great measure to the safety of the vessel, and but for which, on at least one occasion, she might have had a shorter career. The longitudinal framing received great support and assistance from numerous watertight transverse bulkheads.

Unlike modern shipbuilding practice, with its multiplicity of sizes and thicknesses of plates and bars, the inner and outer shell plating of the 'Great Eastern' was $\frac{3}{4}$ in. in thickness; the longitudinal plate girders, $\frac{1}{2}$ in. in thickness; the rivets, $\frac{7}{8}$ in. in diameter spaced 3 in. apart; and the angles, 4 in. × 4 in. × $\frac{5}{8}$ in.

While the beams to both the uppermost and lowermost decks are of exceptional strength, as shown by figs. 59 and 60, the upper deck especially is exceedingly strong.

In addition to the strong upper deck beams, further stiffness and rigidity is given by intercostal plates fitted between them longitudinally, and both the upper and lower surfaces of the beams are plated, making in their entirety a double iron deck.

A general idea of the construction of this marvellous vessel can be obtained from the profile and midship section given.

TURRET DECK CARGO STEAMER (see figs. 62, 63, 64, and 65).

This novel type of cargo steamer first appeared in about the year 1891, and the very fact that since that time over sixty of these vessels have been built, some of them reaching to 450 ft. in length, and also that owners who have had vessels of this type built have in many cases given further orders for new vessels of the same kind, proves that 'Turrets' have shown themselves at least equal, if not decidedly preferable, to the ordinary type of cargo steamers for certain trades.

The first turret steamer was designed and built in the shipyard of the patentees, Messrs. W. Doxford & Sons, Sunderland. Though very different and vastly superior to the notorious whaleback steamer, it is probable that the idea of the turret steamer was first conceived from this vessel. As is now well known, the whaleback steamer was an American invention, and although it was prophesied that this peculiar vessel would revolutionize ship construction, yet the first visit of the first whaleback steamer, the 'Charles W. Wetmore,' across the Atlantic to this country in 1891 was also her last, and she has had remarkably few successors. Fig. 61 shows the main outline and form of a whaleback steamer. The main object in the design was to provide a sea-going vessel with absolutely clear decks, so that if heavy seas broke aboard, there would be no deck erections to carry away, while the peculiar form of the rounded deck would break the force of the sea, and allow it to escape over the sides again above the deck.

The great difficulty of getting along such a weather deck in heavy weather is obvious, the only means facilitating this being a gangway above the deck supported upon turrets at intervals in the length.

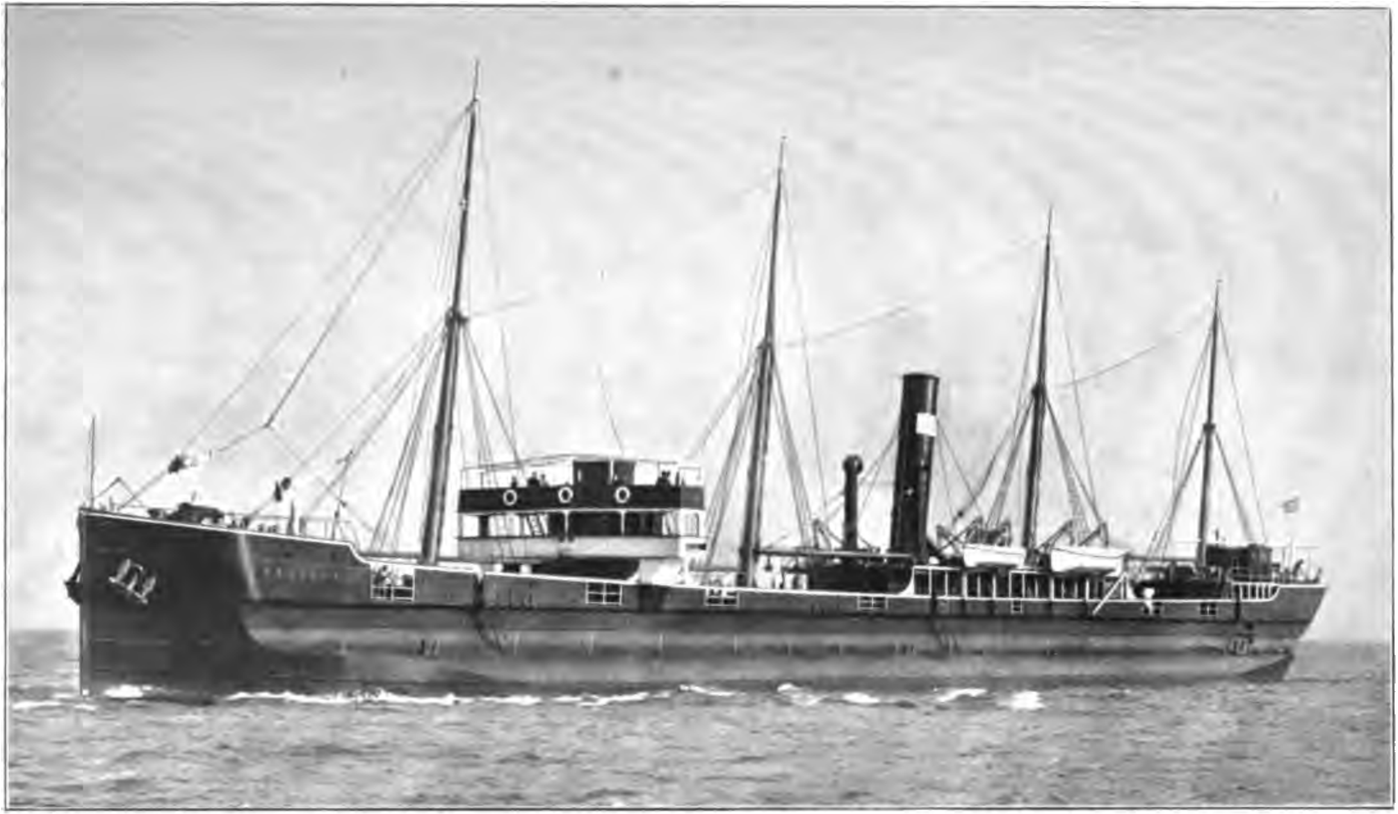
The hatchways are simply holes in the deck, having no coamings, and closed by means of plates which are bolted through the deck. This is objectionable, as there are no means of feeding the holds when carrying bulk cargoes.

The spoon-shaped bow and the form of the bottom, from the stem for some distance aft, makes the hull specially liable to damage when the vessel is pitching in a seaway, owing to the pounding action produced as the vessel falls into the seaway.

In one or two features, the turret steamer is similar to the whaleback. Neither vessels have any fore and aft sheer, and the gunwale is of rounded form in each case. But beyond these two features they are widely different, as is seen by comparing the diagrams of turret steamers, figs. 62 to 65, with the whaleback steamer, fig. 61.

The following are the principal features in the design and construction of the turret deck steamer.

First of all, it may be noted that the form of the vessel below the load water-line is similar to that of any ordinary steamer, the points of difference being above the load line.



'TURRET DECK' CARGO STEAMER.

(*See* FIGS. 62 and 63.)

afforded by the large angle girders just referred to, it is quite admissible that the hold pillars, if of increased strength, should be more widely spaced than is usual in ordinary vessels. The advantage thus given for better stowage is evident. The pillars are usually made of two channel bars riveted back to back, and bracketed at their upper and lower extremities to the deck beams and inner bottom plating.

The turret erection being of a thoroughly substantial character, it is needless to say, in making the strength calculation, that the sectional area of all continuous longitudinal material up to the turret deck is used in arriving at the moment of inertia, hence, with an increased depth of girder, the resulting large moment of inertia is accounted for. At the same time, there being no sheer, and, consequently, relatively less hold space, towards the ends of the vessel, a reduction in bending moment would be the result, were there no turret erection suitable for carrying cargo. Any actual reduction, therefore, in bending moment, as compared with an ordinary vessel, may be ignored, but with increased moment of inertia, it follows that a reduction in the stress per square inch on the topsides may result.

These vessels are usually built with a cellular double bottom all fore and aft, which is of the ordinary construction. The frames are generally of channel or Z section.

Other advantages possessed by the turret steamer may be enumerated as follows:—

There is no possible means of heavy shipped seas finding lodgment on either the turret or the harbour decks, as no closed bulwarks are fitted to any part of the vessel. The turret erection is an ideal feeder to the lower holds in vessels carrying grain and other bulk cargoes, and therefore the danger of a cargo shifting, which is of such frequent occurrence in ordinary vessels, is rendered impossible in the lower holds, while any shift of cargo that might take place in the turret erection itself would have so little effect upon the stability of the vessel as to be unnoteworthy. The rounded form of the gunwale also contributes to the better stowage of these cargoes. By the wide spacing of the hold pillars, a further important advantage is obtained in the matter of stowage. The height of the turret deck (10 to 12 ft. above the load line) on which are situated all the hatches and ventilators, also the engine and boiler casings, companion-ways, etc., is a source of safety and protection to these important parts.

It will be noticed, in looking at the midship sections, figs. 64 and 65, that as far as possible, all connections of plates to one another have been effected by flanging or joggling, thereby dispensing with the usual connecting angle bar and packing. The midship sections show that the floor plates are flanged as well as also the intercostal girders in the double bottom at their upper and lower edges. The edges of the shell plating and inner bottom plating are joggled. By adopting this system, all the plating bears close upon the surface of the material to which it is attached. This confers the great advantage of improving the efficiency of the riveting by

store
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W

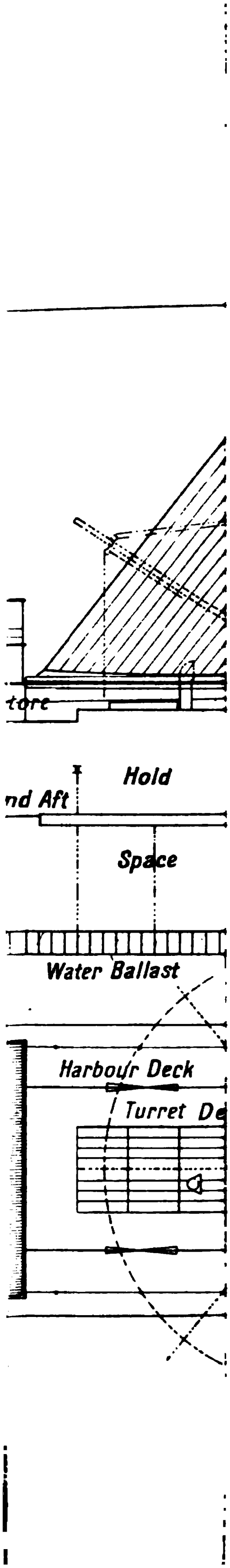
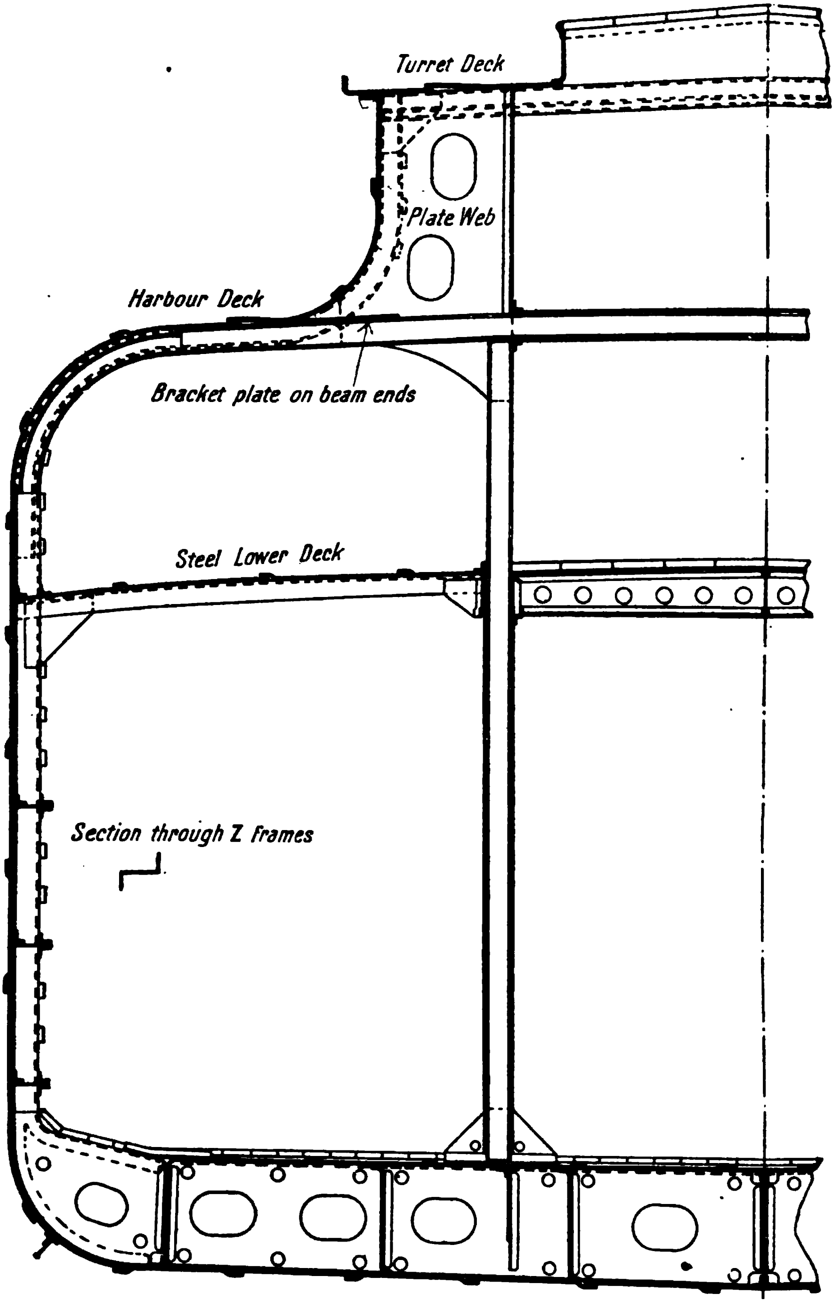

tore
Hold
nd Aft
Space
Water Ballast
Harbour Deck
Turret De

FIG. 64.

MIDSHIP SECTION OF TURRET STEAMER WITH TWO DECKS.


Turret Deck
Plate Web
Harbour Deck
Bracket plate on beam ends
Steel Lower Deck
Section through Z frames

having less thicknesses to rivet, not to mention the great saving by relieving the vessel of the weight of packing. Owing to the strength afforded by the sides of the turret, very long hatchways may be made in these vessels, which is an especial advantage in the loading of certain kinds of cargo.

The additional depth and strength provided by the continuous turret erection makes less necessary any addition to structural strength, on account of the proportion of length to depth.

The turret deck is fitted with the usual loading and discharging gear—winches, derricks, etc.—and following the general tendency in these days, the masts are short, and make no pretence of carrying much sail. Indeed, their chief function is to support the derricks. Objection has been lodged against the turret steamer because of its un-shiplike appearance, but the turret vessel is essentially a cargo steamer, and a deadweight carrier. Moreover, it only resembles, in a more advanced form, the tendency of the ordinary cargo vessel, which, by its full formed hull, shorter masts, and conspicuous smallness of sail, together with its elaborate discharging and loading gear, is fast losing all the features which originally conveyed the idea of a ship. However, as cargo steamers are built to earn freights, any argument against appearance is unreasonable, so long as a satisfactory condition of seaworthiness is assured. Figs. 62 and 64 give a profile and midship section showing the general and structural arrangement of a two-decked turret steamer, and figs. 63 and 65 are similar illustrations of a single-decked turret steamer.

Recognizing the importance of making provision for the carriage of ballast when making long over-sea voyages without cargo, which is so usual an occurrence in these days of keen competition, fig. 63 shows an arrangement for carrying water-ballast proposed by the patentees of the vessel, whereby the draught is increased from the light line shown to a deeper water-line allowing considerably greater immersion and trimming the vessel reasonably by the stern, in order to secure the most favourable conditions for the propeller. Of course, where a huge, deep tank is fitted, such as shown amidships in fig. 63, the bulkheads bounding such tanks require to be most efficiently stiffened, and in the profile are shown the deep vertical webs which the builders fit to these bulkheads, in addition to other stiffening.

The space on the harbour deck at the sides of the turret erection lends itself and is easily utilized for the carriage of deck cargoes, such as timber, etc.

While the freeboards of all ordinary ships which fully comply with the structural requirements of their respective types as laid down by the Board of Trade standard may be determined on a minimum percentage of reserve buoyancy, exclusive of erections which are treated and allowed for separately, the 'turret' and other self-trimming steamers may be treated in a like manner, for although they may differ in design, they still belong to full scantling or spar deck types, or some modification of them, in respect to strength.

It is patent to every intelligent observer that valuable as the turret erection is in affording strength and buoyancy, yet the buoyancy of the turret erection could not reasonably receive the same credit in the matter of freeboard as the same amount of buoyancy distributed over the whole width of the harbour deck as in an ordinary vessel. Hence the Board of Trade Freeboard Tables and Instructions allow as much as 60 per cent. of such buoyancy as being effective in determining the freeboard which is measured from the turret deck, a fact in itself testifying to the value of the turret erection.

A few extracts from the Board of Trade Freeboard Rules regulating the depth of loading of turret deck vessels and vessels of similar types, will no doubt greatly assist in conveying a clear idea of the basis upon which such vessels are treated in the assignment of their load-lines.

"A 'turret' is a strongly constructed continuous erection at the middle line of a vessel, forming with the main or harbour deck an integral part of the hull, and of a breadth not exceeding six-tenths the greatest breadth of the vessel." (Should this breadth be exceeded, the case must be submitted to the Board of Trade.)

"The freeboard, calculated according to the rule given, is in consideration of the turret being continuous. Where the turret is separated within the six-tenths length amidships, additional strength will be required to compensate for this."

"Hatch coamings at least 2 ft. high, and casings to engine and boiler openings at least 4 ft. 6 in. high, to be fitted above the 'turret' deck."

"The volume of the turret to be estimated from a normal beam line drawn through the point where a vertical line at the quarter breadth of vessel cuts the upper surface of the vessel's deck. Where the turret is nearly one-half the breadth of the vessel, and its transverse section is of rounded form at its base, the base line of the turret to be drawn through the point where the vertical line at the quarter breadth cuts the upper surface continued in the same curve as the normal line of beam."

"The reserve buoyancy required by the Tables to be estimated by taking 60 per cent. of the volume of the turret. The height of the turret allowed for is not to exceed 25 per cent. of the moulded depth."

"The moulded depth of the vessel to be taken to be the depth at side from the beam line, as before defined, to the top of the keel."

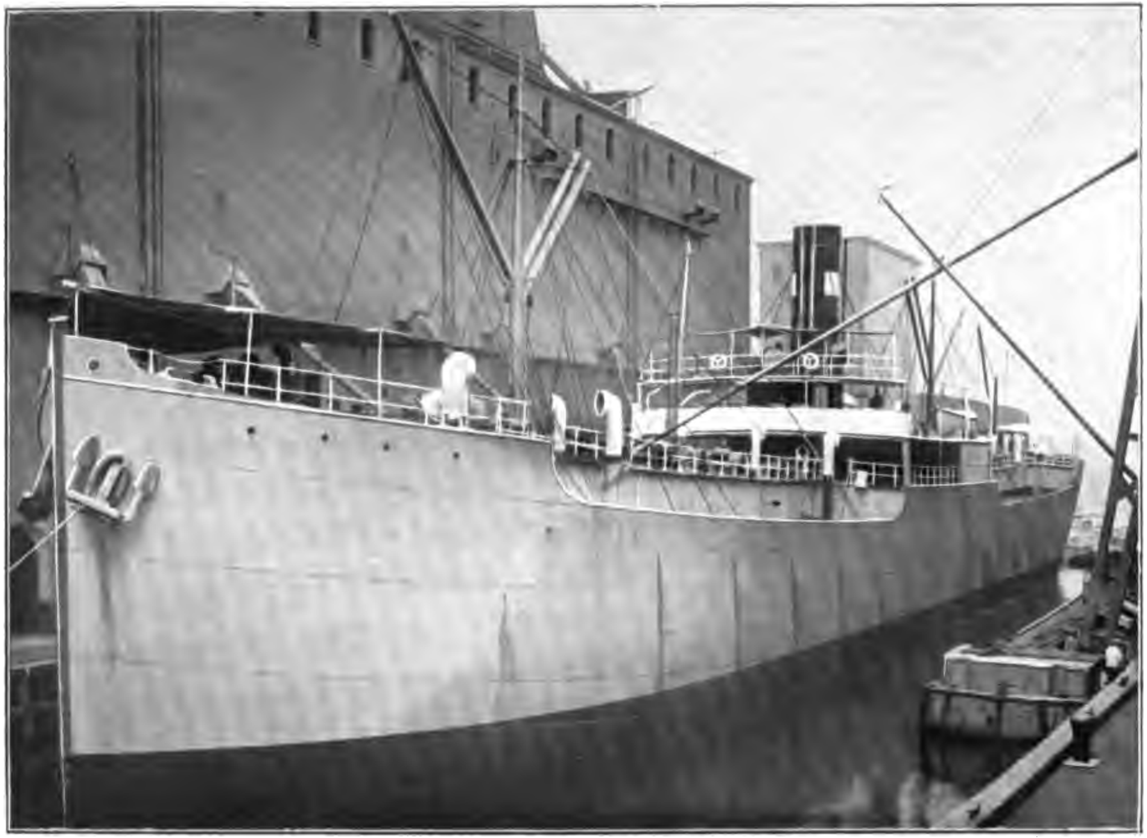
"The transverse and longitudinal strength of the vessel to be regulated by that required for a 'three-deck' or 'spar-deck' vessel of the same length, breadth, moulded depth, and coefficient of fineness."

TRUNK STEAMERS.

Figs. 66, 67, 68, and 69 are plans illustrating in profile and midship section what is known as the 'Trunk' steamer.

The inventors of this type of vessel are Messrs. Ropner & Son, the

PLATE II.]



'TRUNK' CARGO STEAMER.

(*See* FIG. 66.)

well known shipbuilders of Stockton-on-Tees. The trunk steamer is essentially a cargo vessel which possesses special facilities for the stowage of bulk cargoes, and advantages in the navigation of the vessel. On referring to the midship section, fig. 67, it will be seen that, up to the gunwale, this vessel is in every respect similar to the ordinary type of cargo vessel. She has a cellular double bottom, and is framed on the web frame system, thereby dispensing with a tier of hold beams, and leaving the whole space perfectly clear, with the exception of the hold pillars, which are widely spaced. Instead of web-frames, the deep-frame system may be adopted. In addition, these vessels have a poop, bridge and forecastle constructed in the usual way.

The special feature of this vessel is the trunk erection. This trunk is strongly framed and plated, and can be made thoroughly substantial. It extends from the poop to the bridge, and from the bridge to the forecastle, into each of which the sides of the trunk are scarphed. The height of the trunk is about 7 ft.—that is, the height of poop, bridge and forecastle—with which erections the top of the trunk forms a continuous deck. The breadth of the trunk is about half the beam of the vessel. Strong, through beams are placed where necessary, at intervals at the base of the trunk (see figs. 66 and 67). These strong beams greatly assist in maintaining the transverse strength. Apart from these strong beams, the trunk space is entirely open to the lower hold, and, as the midship section shows, the ordinary main deck beams are cut at the sides of the trunk. This apparent weakness, however, is fully overcome by the strong connection made between the trunk sides, the beams, and the pillars. (See fig. 67.) First of all, the deck plating is flanged into the trunk side. The hold pillars are of channels, or tee bars, fitted back to back, one of which bars extends some distance up the trunk side plating to which it is riveted, and further, the pillars are bracketed to the deck beams and deck plating, as shown. Thus the trunk sides, being thoroughly connected to and scarphed into the poop, bridge and forecastle, and supported as they are by extra strong hold pillars, afford ample strength for carrying the beam ends and supporting the main deck.

The trunk side frames, and the beams supporting the trunk deck, are all of about the size of the main frames of the vessel, and connected by brackets as shown in figs. 67, 68, and 69.

As all the principal hold hatchways are situated upon the trunk deck, the trunk deck beams are necessarily cut at the hatch sides, but, as the midship section shows, the hatch sides are well supported by large web plates fitted between the trunk deck and main deck strong beams. The deck area of the trunk deck is increased by extending the deck plating about 1 ft. beyond the trunk sides, and this being practically the navigating deck, hand rails are placed along each side for protection as shown.

The great advantage of having the navigating deck 9 or 10 ft. above the load water-line is a feature which every seaman can appreciate.

Moreover, as all hatchways, ventilators, and deck openings are situated either on the trunk deck, or on the poop, bridge, or forecastle, the protection which is afforded to these important parts, including the engine and boiler openings, is very apparent.

In the loading of bulk cargoes, the trunk forms an excellent feeder to the main holds in addition to possessing the facility for self trimming. The main deck is either fitted with open rails, or closed bulwarks of the usual form, as may be desired. Owing to the substantial nature of the hold pillars, and the excellent support they give to the trunk side and main deck beams, they are spaced at wide intervals apart, and by this means the possibilities of broken stowage are minimised. The main deck outside of the trunk is well adapted for the carrying of timber, cattle, or other deck cargo. Fig. 68 shows the trunk of one of these vessels specially arranged for coal cargoes, the sloping trunk sides further facilitating the self-trimming propensities of the vessel. In some cases, cargo skids or platforms at the sides of each hatch are fitted, extending from the level of the trunk deck to the sides of the vessel, for convenience in discharging cargo. Fig. 69 illustrates another special arrangement of trunk particularly designed for the purpose of carrying rice cargoes. As rice cargoes are very liable to damage owing to the vessel sweating, the diagram shows gutter-ways at the base of the trunk (G in fig. 69), by means of which the moisture which drips down the trunk sides is collected and led off by scuppers down into the bilges.

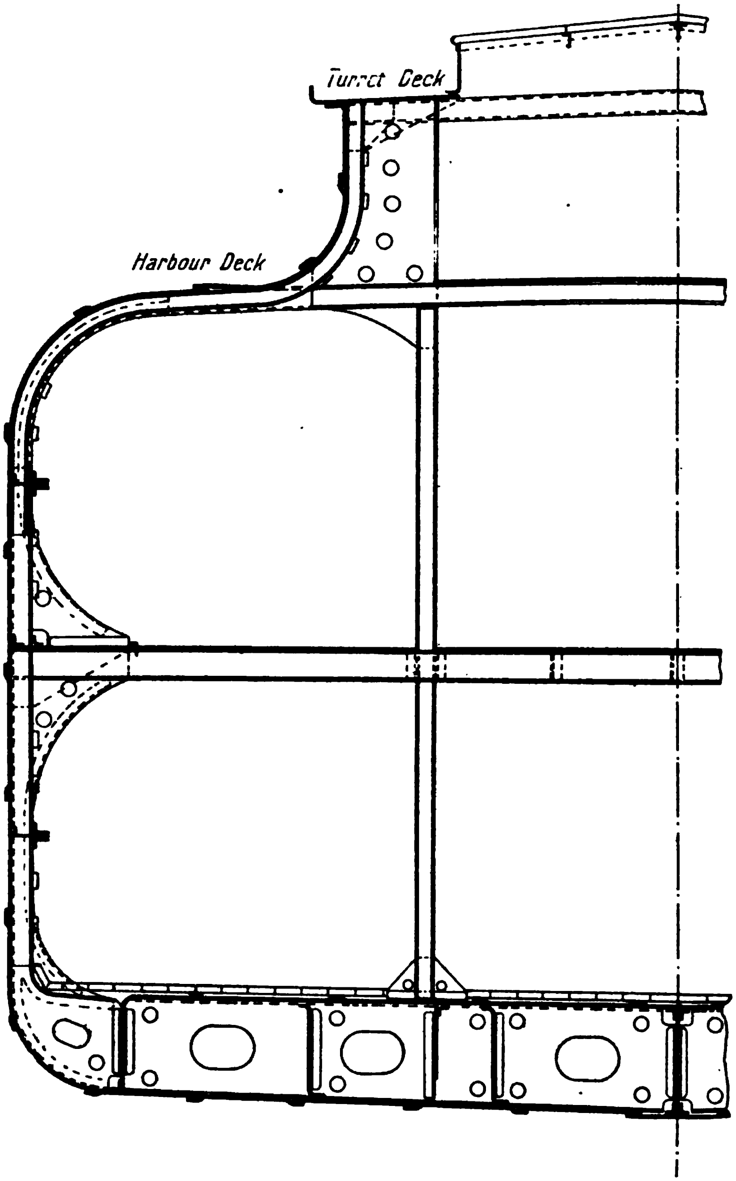
The cargo ports, P, shown on the sides of the trunk are sometimes fitted for the purpose of facilitating either the loading or unloading of such cargoes as can be readily passed in or out of such ports. They also serve the useful purpose of assisting ventilation. The other principal structural features of this vessel are clearly illustrated in the accompanying diagrams.

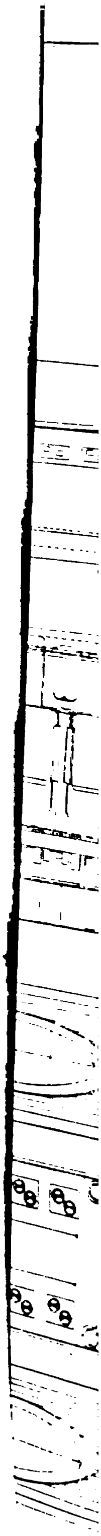
PRIESTMAN'S SELF-TRIMMING STEAMER.

Fig. 70 is a profile, and fig. 71 a midship section illustrating another type of self-trimming steamer. The design is the patent of Messrs. J. Priestman & Co. of Sunderland. The principal feature is an erection about 5 ft. in height extending from stem to stern. The top breadth of this erection is about half the moulded breadth of the vessel, and it forms the navigating deck. The hull from the keel up to the gunwale is of the ordinary form and construction. The diagrams illustrating this vessel show her to be built upon the web-frame system, thereby dispensing with hold beams, but if preferred, deep framing might be adopted instead, or the ordinary frame and reverse bar (or some equivalent) together with widely-spaced hold beams. But as it is necessary for trimming purposes that the erection be in free communication with the main hold, the transverse strength of the vessel in way of the main deck is maintained

FIG. 65.

MIDSHIP SECTION OF A TURRET STEAMER WITH ONE DECK AND A TIER OF WIDELY-SPACED HOLD BEAMS.


Turret Deck
Harbour Deck



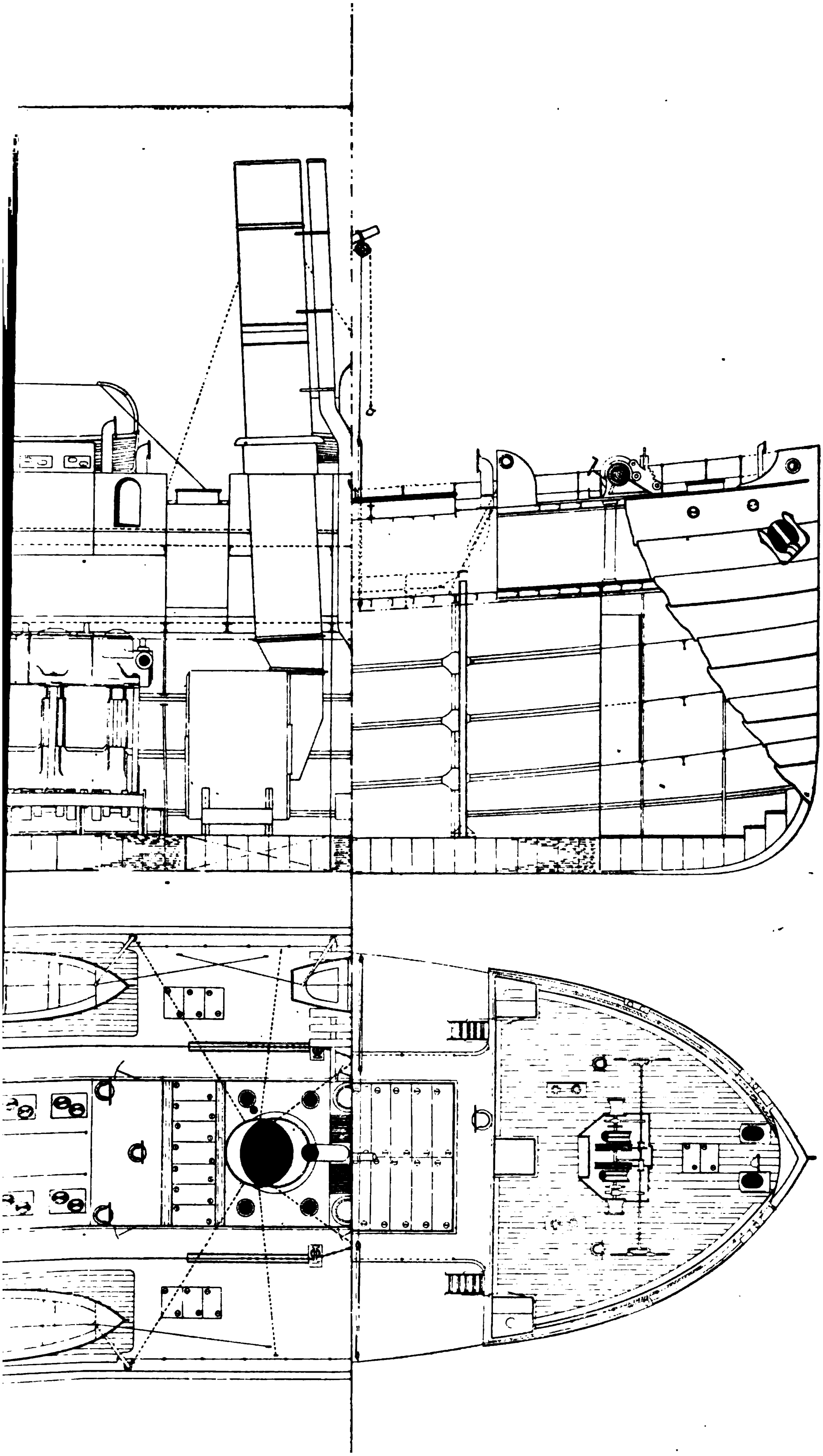


FIG. 70.

RIMMING STEAMER.

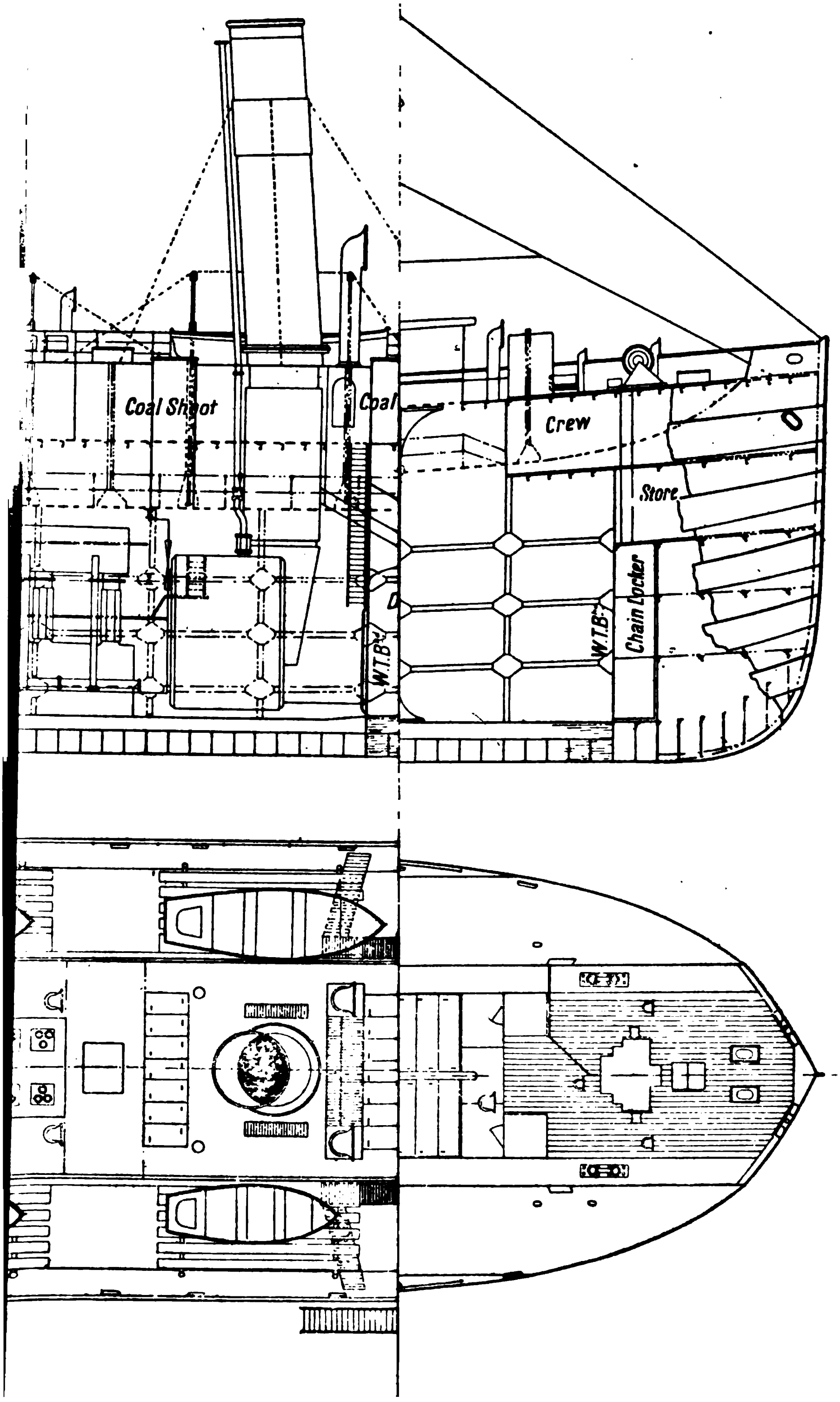
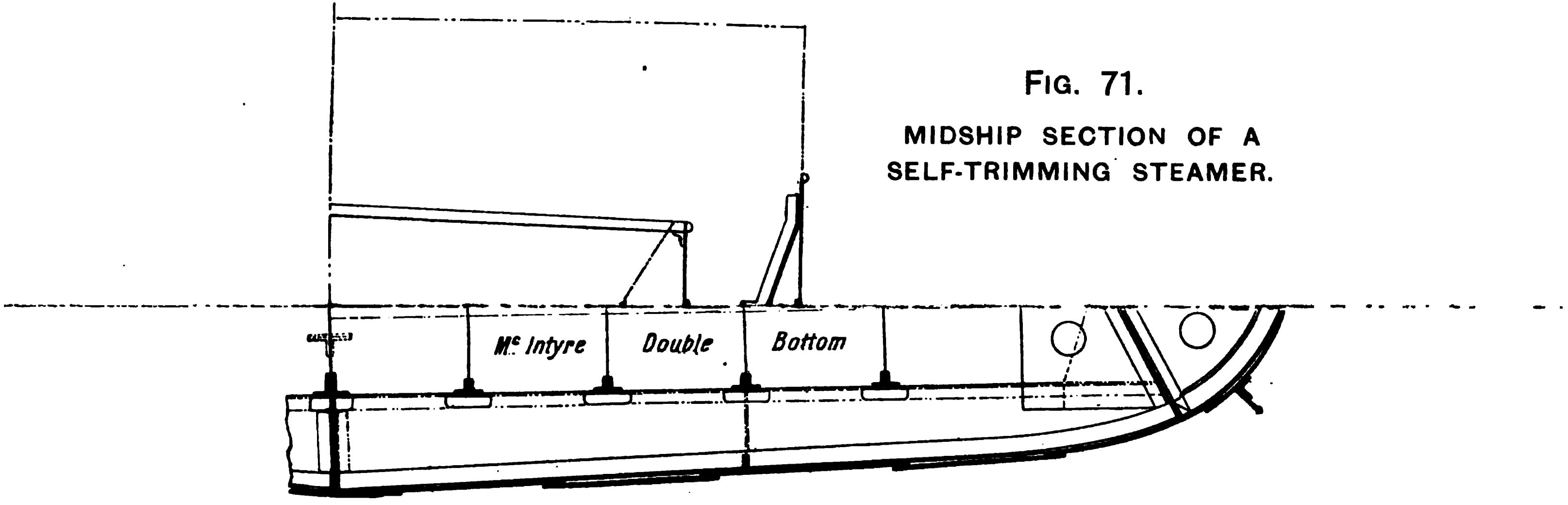
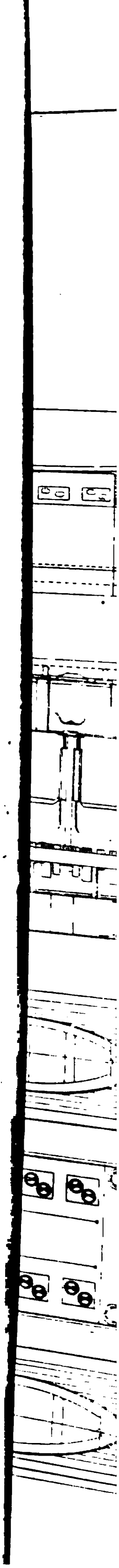
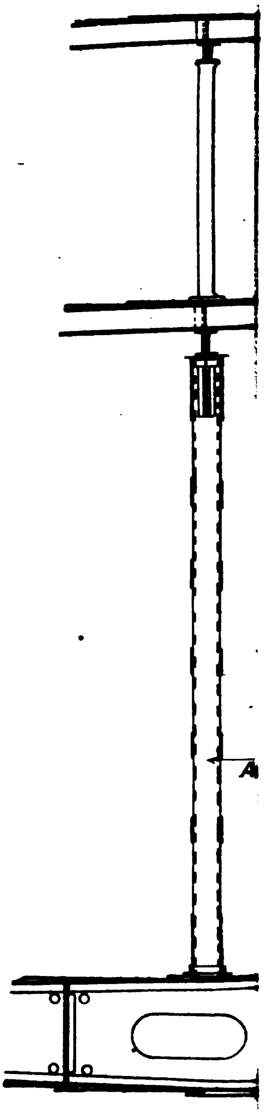

Coal Shoot
Coal
Crew
Store
Chain Locker
W.T.Bd
W.T.Bd

FIG. 71.

MIDSHIP SECTION OF A SELF-TRIMMING STEAMER.


Mc Intyre
Double
Bottom




A

by means of widely-spaced bulb plate beams well kneed to the web frames, and each supported by two hold pillars formed of double channel bars fitted back to back, which are bracketed at the top to the beams, and at the bottom to the tank top-plating.

The sides of the erection slope from the navigation deck to about 2 ft. from the gunwale, in order to increase the facility for self-trimming. The main frames from the tank side to the gunwale are channel bars.

The self-trimming erection also is framed by means of channel bars which are kneed on to the main frames, and extend continuously from one side to the other, excepting in way of the hatches. Support is afforded to the sloping sides of the erection by means of large bracket plates on every strong beam. (See fig. 71.)

The navigation deck is supported by large web plates fitted between this deck and strong main deck beams immediately above each hold pillar. (See fig. 71.) It is also further supported by means of large bracket plates placed in a fore and aft direction at the angle of the navigation deck with the sloping sides. (See the profile, fig. 70, and the section, fig. 71.) All hatches, ventilators, deck openings, including the engine and boiler casings, are upon the navigation deck, and thus considerably more elevated than they would be in a vessel of the ordinary type. The erection forms a natural feeder to the hold, with which it is in free communication, and is therefore specially adapted for the carriage of bulk cargoes. The sloping sides of the erection obviously greatly facilitate the self-trimming of such cargoes. An ordinary open rail is fitted round the main deck for purposes of protecting the crew. As the sloping side of the erection offers little resistance to the inroad of beam seas which are liable to sweep over the vessel, a closed iron bulwark is fitted to the navigation deck, well stayed by means of bars of tee iron section or something equivalent. This not only affords protection to the seamen in their duties in navigating the vessel, but keeps the upper deck drier than it otherwise would be. The erection being continuous from stem to stern with the top and sides blended into the main hull by the stringer plate being flanged as shown in the midship section, and the erection side plating flanged on to the navigation deck, there is no doubt as to the substantial nature of the self-trimming erection. Further, the hold pillars being widely spaced, the possibility of broken stowage of cargo is greatly reduced.

While the diagrams show this vessel to be built with a M'Intyre double bottom all fore and aft, excepting under the engines and boilers where ordinary floors are fitted, a cellular double bottom might have been adopted equally well had such been preferred. The sides of the self-trimming erection are specially arranged for the carriage of timber on deck; special provision for securely lashing the same from side to side of the vessel is provided by bar iron posts bracketed to the deck, spaced at intervals throughout the length as shown in the profile.

Some New Features in Modern Shipbuilding.

While several smaller changes and improvements have taken place in recent years in many of the details of ship construction, probably the greatest and most startling of these changes, and, it may be truly said, improvements, have taken place in a number of vessels designed by Mr. H. B. Wortley for the 'Ocean Steamship Company' of Liverpool, managed by Mr. Alfred Holt. When first these innovations were propounded, they were looked at in consternation by many experts, but the fact that a number of these vessels have been built, and have sailed several round voyages to China and back in all weathers and seasons, and have had unstinted praise lavished upon them by the men who have handled and manœuvred them, in addition to the compliment that some of the features have so commended themselves to practical shipowners that they have reproduced them in their new vessels, proves that the advance is in the right direction. The principal innovations referred to are as follows:—

1st. No sheer.

2nd. More widely spaced transverse framing.

3rd. The substitution in the main hold of two pillars instead of the usual numerous stanchions, and a modification of the same system in the other holds.

4th. The usual form of stern frame for single screw vessels dispensed with, thereby enabling the shipbuilder to get rid of much useless material (and hence weight) in that locality known as the dead-wood in wooden vessels, at the same time improving the steering qualities, while a special arrangement has been introduced to carry the rudder, which also is of special design.

5th. Cement. The bottom of the vessel inside the ballast tanks is not cemented.

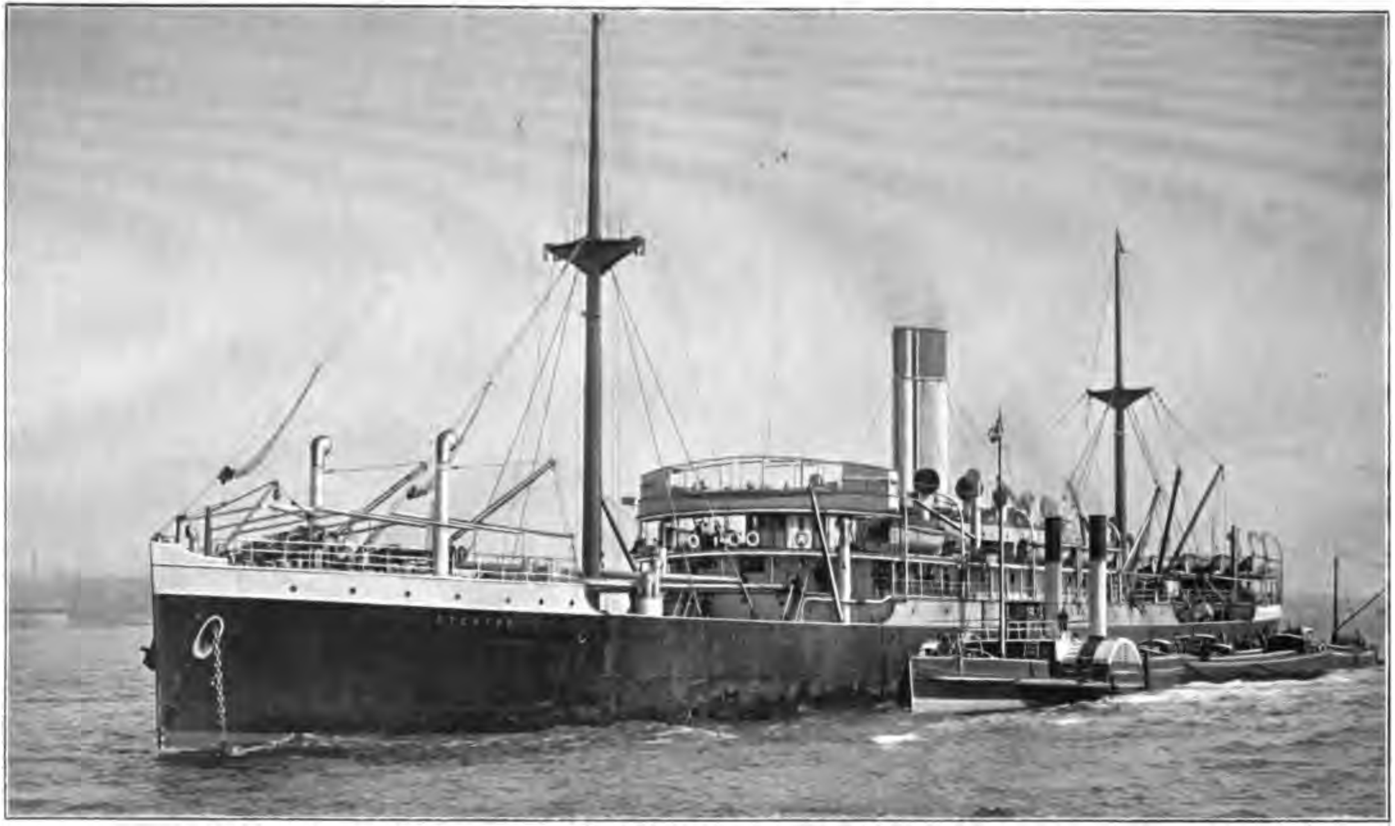
Reference to figs. 72, 73, 74, and 75, graphically illustrates most of the points just mentioned. It is advisable, however, to look more particularly into the features or innovations just enumerated in order to determine more fully what results are entailed in their adoption.

1st. Sheer.—That sheer is not given to a vessel for purposes of strength should be clearly understood, for while increased depth over the midship length undoubtedly contributes to increased effective longitudinal strength, yet the increased depth which sheer gives towards the extremities is utterly useless for this purpose, as the longitudinal bending moments decrease from midships towards the ends.

The value of sheer lies in the increased reserve buoyancy which it provides towards the ends of a vessel, affording increased lifting power, when she is labouring among head or following seas, which in turn means a drier deck, and greater protection to the crew. Consequently vessels with less than the Board of Trade standard sheer are penalized by having

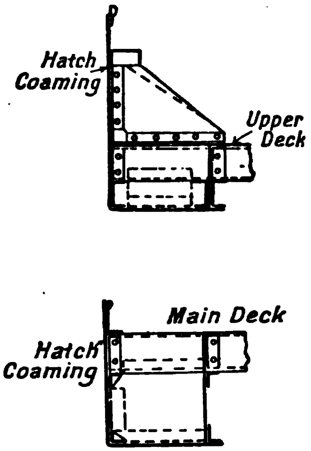
PLATE III.]

[*To face page* 146.

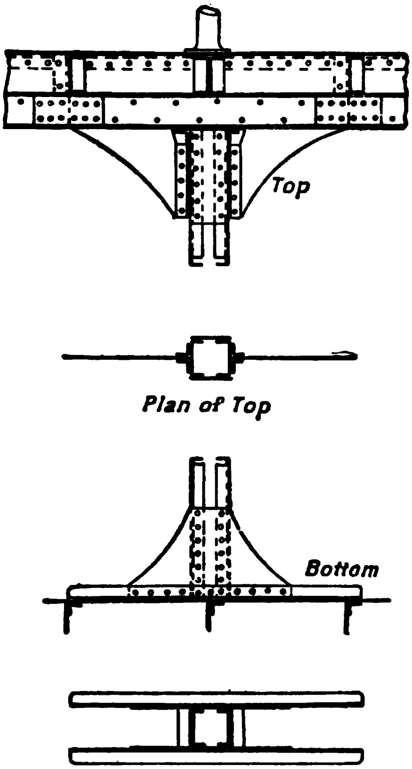


A TYPICAL CARGO STEAMER.

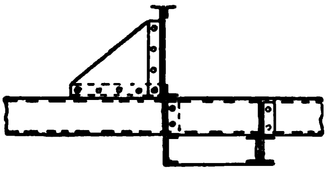
S.S. 'STENTOR,' OCEAN STEAMSHIP COMPANY. (*See* FIG. 72.)


Hatch Coaming
Upper Deck
Main Deck
Hatch Coaming

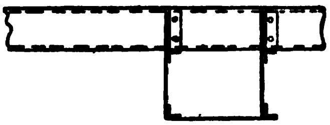
Section through Main Hold Hatch Side in way of Pillars.


Top
Plan of Top
Bottom
Plan of Bottom

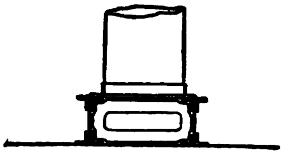
Top and Bottom of Pillars in After Main Hold.



Section at A B (see fig. 72).



Section at C D (see fig. 72).



Section through Stool under Main Hold Pillars.

Fig. 74.—Detail Sketches of Vessel illustrated in fig. 72.

the freeboard increased, while vessels with sheer in excess of the standard obtain a reduction in freeboard. Spar and awning deck vessels are exceptions to this rule.

Now if by any other means a vessel can be provided with ample reserve buoyancy at her ends, the same purpose for which sheer is given will be served, and it will be better from a structural point of view to take the increased depth which a certain sheer would have provided, and add it uniformly all fore and aft to the depth of the ship. By this means not only is the total amount of reserve buoyancy above the upper deck maintained, but, as previously pointed out, the longitudinal strength of the ship is effectively increased.

In these special vessels with which we are dealing, the necessary reserve buoyancy at the ends is abundantly supplied by means of a high poop and forecastle (about 9 ft.), which cover a considerable length at each end. Sheer is therefore unnecessary.

In addition to the aforementioned erections, a well-constructed and efficient bridge covers a considerable portion of the middle length, including the engine and boiler openings. In order to avoid the appearance of being 'hog-backed,' which might result from a horizontal deck, a sheer is given to the bulwark line only, the sight edge of which is continued from stem to stern.

2nd. Widely-spaced Transverse Framing.—Whether a load line be assigned to a British vessel by a registration society or the Board of Trade, as previously stated, she must come under the test of Lloyd's 1885 Rules. It is therefore reasonable to expect that if the transverse frames be more widely spaced than are specified in these rules for any particular size of vessel, compensation, or, in other words, equivalent strength must be introduced, and this is done in the vessels we are describing in the following manner:—

First.—As the transverse frames are spaced 36 in. apart instead of 27 in.—the maximum given in Lloyd's present Rules—the required transverse stiffness is obtained by increasing the depth of the framing; and as these ships are built on the deep frame principle, this is easily done by increasing the depth of the athwartship flanges of both the frame and the reversed bar. As fully described in Chapter V., in dealing with the strength of girders, an increase in the depth of the deep framing not only increases the sectional area, but the moment of inertia also in a greater proportion than the sectional area. So that although the individual frames are heavier, their decrease in number ought to result in a lighter total weight of framing.

Second.—If widely spaced transverse frames be adopted in combination with the ordinary longitudinal framing, greater areas of unsupported shell plating would exist over the whole of the immersed surface of the hull, and the tendency would be for the shell plating to fall hollow, owing to the enormous pressure to which these areas would be subject. Something must therefore be done to provide the necessary rigidity. This can be effected by somewhat reducing the sectional area of the large cumbersome side stringers required by rule, and compensating for this reduction by fitting additional side stringers of a more compact form. In this way the longitudinal strength would be preserved, while, at the same time, such strength would be more uniformly distributed, thereby reducing the area of unsupported shell plating. Fig. 73 shows an excellent arrangement of side stringers.

Every strake of shell plating has a stringer upon it, extending throughout its whole length, thus converting each strake with its accompanying stringer into a combined girder. The excellency of such an arrangement needs no further comment.

Third.—When the foregoing system of adopting additional longitudinal girders in combination with widely spaced transverse framing is not carried out, the required stiffness to the shell plating can only be obtained by increasing its thickness. Indeed, in the Board of Trade Freeboard Tables and accompanying Rules, the following paragraph is found relating to this aspect of a vessel's strength :—

"If the frame spacing be increased one-fourth, the thickness of all the plating, excepting garboard and sheer strakes, should be increased by $\frac{1}{20}$th of an inch over the thickness required in the standard ship. Other increases in spacing should be dealt with in the same proportion."

3rd. Hold Pillars.—Pillars, or some substitution for the same, are an absolute necessity in all ships. In vessels of comparatively small beam, middle line pillars alone are sufficient, but in larger vessels having greater breadth, the beams (decks) require additional support between the middle line and their connection to the frames. In figs. 72 and 73, which illustrate a vessel of 52½ ft. in breadth, both middle line and side or quarter pillars are required by Lloyd's Rules, but as shown in the diagram, these are entirely omitted with the exception of those shown in the profile, which are of exceptional construction and strength. In the main hold, which is the longest in the vessel, two hollow plate pillars, 21 in. in diameter, support the deck, the supporting strength being distributed throughout the length of the hold space by a very strong box girder well connected to the deck and beams and to the bulkhead by means of large brackets.

The thrust of these two pillars is distributed over the bottom of the vessel by means of a stool to which they are connected by angle rings—the stool in its turn being well connected to the inner bottom. (See figs. 72, 73, and 74.)

The main 'tween-deck pillars are 12 in. in diameter. They are connected to the deck at their lower extremity by an angle ring, and to the upper deck by a girder made up as shown in fig. 74 of plates and channel bars. This girder comes alongside the upper deck hatch coaming plate, which itself forms one web of the girder, and is extended along the upper deck over the full length of the main hold, so as to rest upon the bulkheads at the extremities of the space. A couple of angle bars along the top edge of this plate (excepting in way of the hatch) add additional stiffness to the girder. The continuity of these deck girders or stringers is preserved all fore and aft, though somewhat modified in form on account of the shorter lengths of the remaining holds. For a similar reason, a modification is made in the construction of the pillars. These as shown in figs. 73 and 74, are made up of two channel bars, assisted at intervals in their height by plate ties, and well connected to the deck girders and tank top by means of large brackets at the upper and lower extremities.

The 'tween-deck pillars for these holds are made of solid round iron, 6 in. in diameter, with large palms to both their feet and heads, thereby permitting a good rivet connection.

4th. Stern Arrangement.—The great innovation in the arrangement of the stern for the efficient support of the propeller, and in the construction of the rudder and the manner in which it also is supported, is clearly illustrated in fig. 75. Unlike the ordinary stern frames in single screw steamers, both forgings and castings are conspicuous by their almost entire absence, the only item of this kind being a comparatively small steel casting for the boss. This extends, as shown in fig. 75, from a watertight flat immediately above the boss to the lowermost extremity of the aftermost watertight bulkhead, and is riveted to both the watertight flat and the bulkhead through palms on the casting.

The remainder of the propeller aperture arch is constructed of a U-shaped Siemens-Martin steel plate 1 in. in thickness. By this arrangement, both the longitudinal and transverse framing are thoroughly connected to the stern plating as shown by the detailed sketches in fig. 75. Such an arrangement at once dispenses with a very considerable amount of weight, and makes the structure of the stern a thoroughly combined and compact one, and experience has proved these vessels to be remarkably free from vibration. Loose rivets, so prevalent in ordinary stern frames, have so far been practically unknown.

The stern post proper, upon which the rudder is shipped, consists of a wrought iron tube, 1 in. in thickness and 21 in. in diameter; and to afford additional strength to the lower part of the post where most of the stress from the rudder is sustained, a doubling or liner of the same thickness is fitted.

The rudder also is of unusual design. It contains no forgings nor castings excepting in the neighbourhood of the coupling, where a steel casting is necessary in order to obtain an efficient connection with the rudder stock. Apart from this, the rudder is entirely made of plates and angles (see fig. 75), and is designed to offer the least resistance to propulsion.

This rudder possesses the further advantage, owing to its form, of having the interior accessible in every part. The socket in the rudder into which the bottom of the stern post fits, is made of Siemens-Martin steel, with a white metal lining for a working surface.

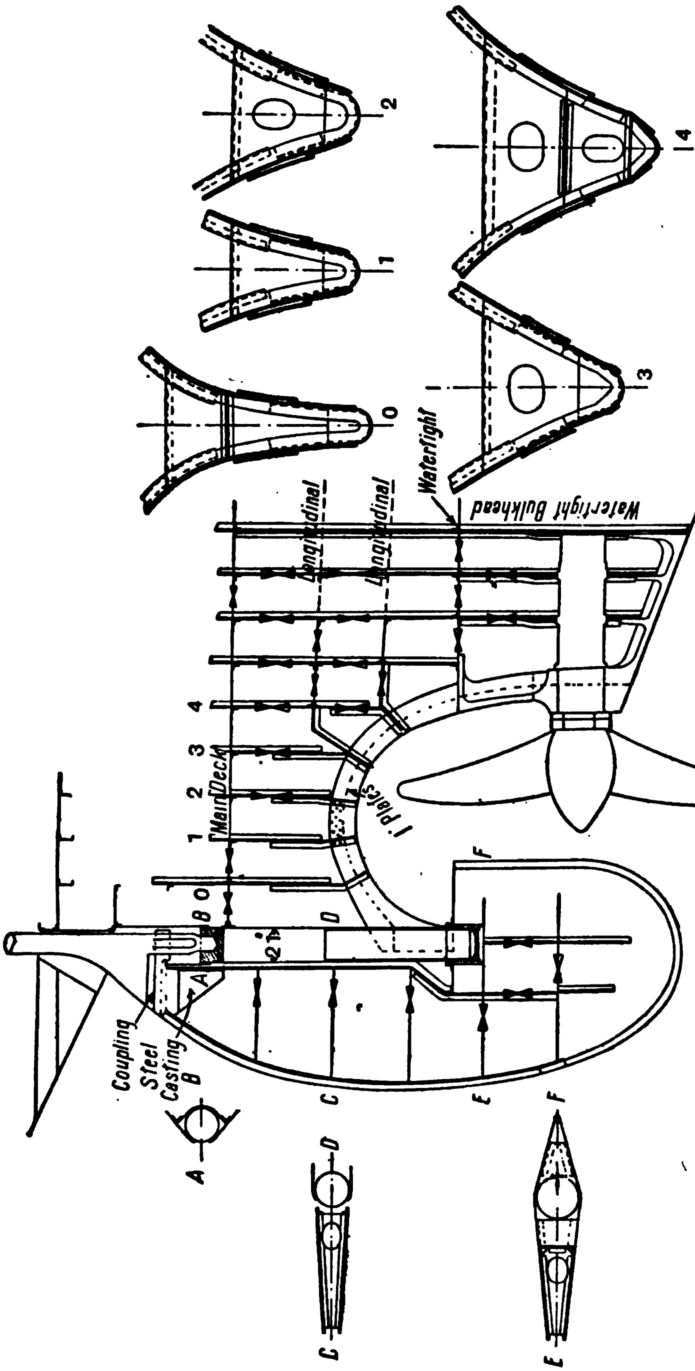

Coupling
Steel Casting
A
B
C
D
E
F
Main Deck
Longitudinal
Longitudinal
Watertight
Watertight Bulkhead
plates
0
1
2
3
4

FIG. 75.—Stern arrangement dispensing with ordinary Stern Frame, and also Special Design of Rudder (for vessel illustrated in fig. 72).

For this construction of stern frame and rudder, it is claimed that a saving of at least 10 tons of weight is effected in vessels of this size.

These ships have proved exceptionally easy to handle, and thus the arrangement just described, in addition to its structural efficiency, enhances manœuvring powers.

5th. Cement.—A great saving of weight is effected in these vessels by the disuse of cement as ordinarily applied in cellular double bottoms. The inner surfaces of these tanks are well preserved by being coated with cement wash only, which must naturally be renewed periodically.

The use of cement has been more fully discussed in Chapter VIII., which deals particularly with the subject of 'Maintenance.'

Steamers for carrying Oil in Bulk.

The great development which has taken place in comparatively recent years in the exportation of petroleum from Black Sea and American ports, has naturally led shipowners to consider what was the most economical way in which this cargo could be carried, and notwithstanding the prejudice and suspicion of danger which first existed in the minds of many interested shipowners and others against the carrying of oil in bulk, as well as the difficulties which presented themselves, yet the great advantage over that of carrying oil in cases and in barrels led to the experiment being made. The first ship in which oil was carried in bulk was fitted out at the shipyard of Messrs. Craggs & Co., of Middlesbrough. The vessel was an ordinary cargo steamer, into the holds of which huge oil-tight tanks were fitted, shaped to the form of the vessel. In these tanks the oil was carried. Since then, a large number of vessels have been specially built to engage in this trade, and great developments have been made in the construction and adaptation of ships for this purpose, due in no small measure to the Bureau Veritas Classification Society, whose experience was probably unequalled in the early days of tank steamers.

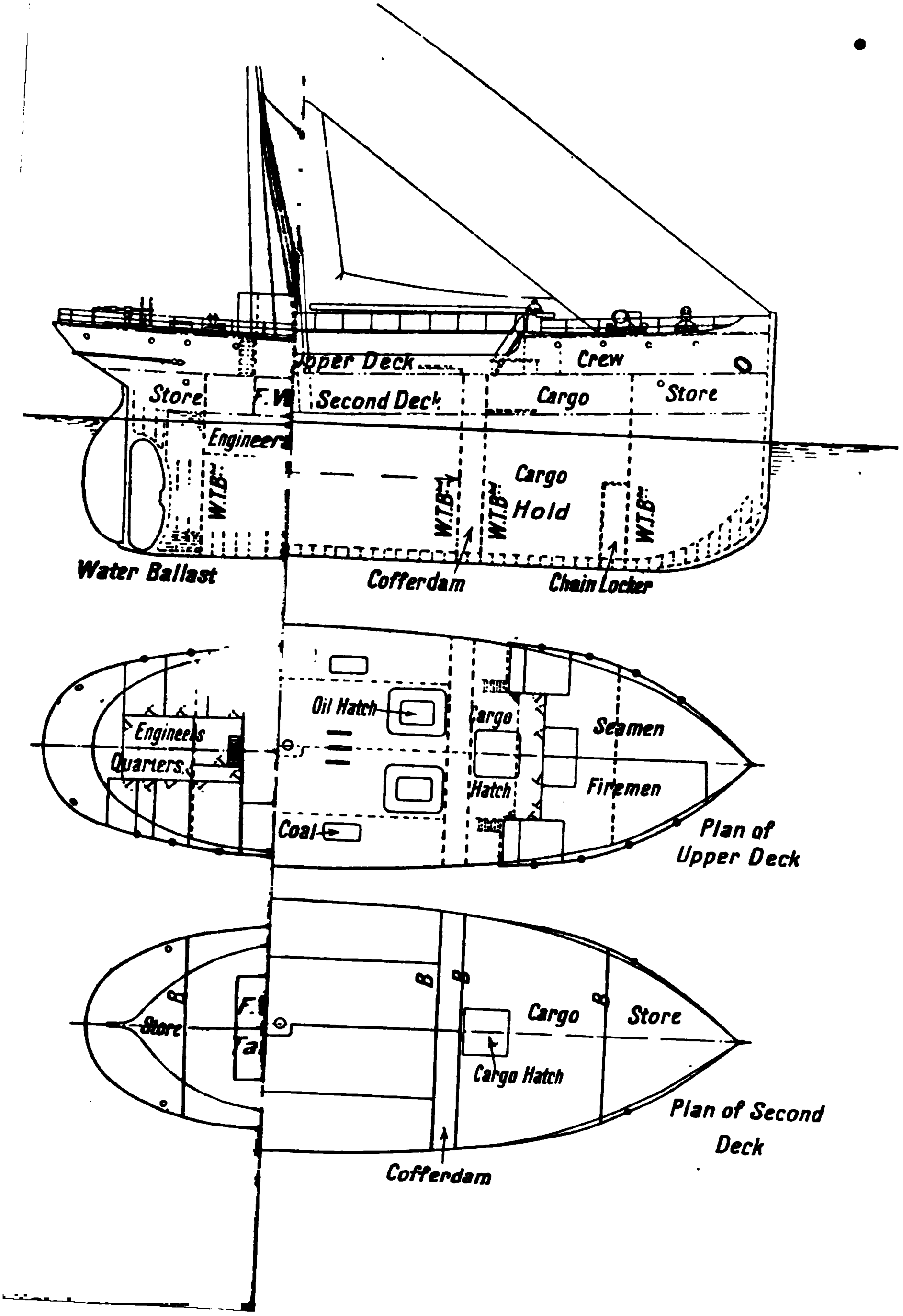
Figs. 76 and 77 are profile illustrations of two modern oil steamers built by Messrs. Armstrong, Whitworth, & Co. of Newcastle-on-Tyne, who have earned a great reputation in building this class of vessel. Fig. 78 is a midship section showing the disposition of the material in the construction. Before briefly observing the principal features in the arrangement and construction of oil steamers, a few points especially peculiar to vessels engaged in carrying oil in bulk, which affect the design to a considerable extent, and need to be well remembered in the process of construction, may be first noted.

1st. The gas which arises from petroleum, especially crude oil, in combination with the atmosphere becomes highly explosive at a certain point.

2nd. If the temperature of the oil is increased, it is subject to expansion.

3rd. While, in an ordinary cargo vessel, the cargo bears directly upon

BULK.


Upper Deck
Crew
Store
F.W.
Second Deck
Cargo
Store
Engineers
W.T.B.
W.T.B.
W.T.B.
Cargo
Hold
W.T.B.
Water Ballast
Cofferdam
Chain Locker
Engineers
Quarters.
Oil Hatch
Cargo
Hatch
Seamen
Firemen
Coal
Plan of
Upper Deck
B
B
B
B
Store
F.
Ta
Cargo
Store
Cargo Hatch
Plan of Second
Deck
Cofferdam

the transverse and longitudinal framing, the weight chiefly being taken by the floors, in a modern oil steamer the oil extends out to the outside shell plating, and, like all fluids, exerts its pressure square to the surface against which it comes into contact.

In addition to this, there is the increased pressure due to the inertia of the cargo itself, as the vessel rises and falls in her pitching movements, and, to a less extent, in rolling.

4th. With liquid cargoes, like oil or water carried in bulk, there is always a certain amount of danger in the process of filling up the tanks, if the vessel is deficient in stability. Evidently, should the vessel, through lack of metacentric height in any condition, take a list, the free surface of the liquid in a partially filled tank may tend only to increase the heeling, for the more the vessel inclines the more will the liquid shift.

From the principal points just enumerated, it follows that oil-tightness, structural strength, and stability are of the utmost importance in vessels carrying liquid cargoes in bulk, and suitable provision must be made for the expansion of the oil. Nothing is more essential than that the riveting be most efficiently performed, and the workmanship generally of the very highest character. Bad riveting spells doom to an oil steamer, for one can easily imagine, taking one aspect of the danger alone, what terrible results might, and indeed have, accrued owing to leaky bulkheads, and the oil or gases finding their way into the engine and boiler compartments. More disasters from explosion and fire have happened to oil steamers than from any other cause. A loose rivet should never be caulked, but the rivet removed, and the hole re-riveted. It is also necessary in order to obtain and maintain oil-tightness, that the very best form of rivet should be adopted. Two kinds of rivets have proved very satisfactory for oil-tight work, the pan-head rivet with the swollen neck, and the plug-head rivet (see fig. 90). In adopting either of these, the plating ought to be countersunk, so as to better receive the swelled neck. The drift punch must be rigorously forbidden. Blind holes should be rimed fair and not torn open, as so often is done with the drift punch. The spacing of rivets for oil-tight work should never exceed 3 to 3½ diameters of the rivet.

In all vessels carrying liquid cargoes in bulk in the hold spaces, the strain upon shell plating and bulkheads is very great, owing to the pressure of the liquid increased by the inertia of the cargo when pitching and rolling. The bulkheads should therefore be amply stiffened and supported. The rivets through the flanges of the frames connecting the shell, which largely bear the strain due to pressure on the shell plating, should be spaced not more than six diameters apart.

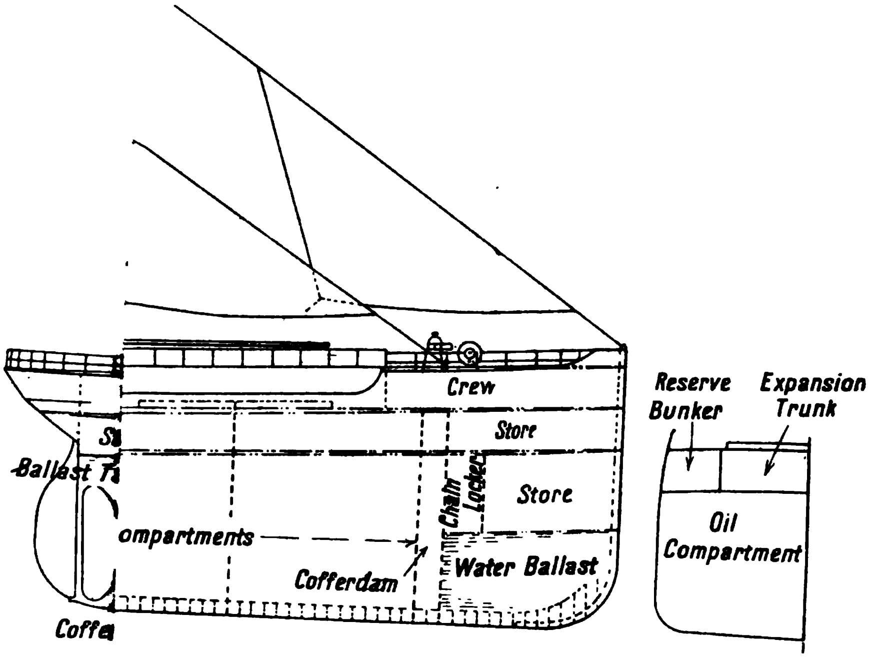
In all hold spaces in which liquid cargoes are to be carried, the middle line bulkhead should be fitted all fore and aft through such spaces, extending from the keel to the deck forming the crown of the tank, or to the top of the expansion trunk. This bulkhead should be strictly oil- and water-tight. It is valuable because it contributes strength and unites and supports the deck and bottom plating, but it is most valuable from a stability point of view, its principal function being to minimise the shifting of cargo in the event of the vessel taking a slight list in the process of filling up the tanks. It ought never to be required for this purpose when the vessel is at sea, for all tanks ought to be completely filled before proceeding upon any sea voyage, however short it may be. To proceed to sea with an oil or a water-ballast tank only partially filled is to invite disaster, for such display of ignorance has not infrequently resulted in bulkheads being torn down and other extensive damage wrought. A longitudinal bulkhead also reduces the inertia of the cargo when rolling in a seaway. Long hold spaces in a fore and aft direction are most undesirable in any vessel carrying liquid cargo in bulk because of the rapidity with which such cargoes shift should the tank not be completely filled, and the great inertia which huge volumes of such cargo possess. Such danger as described can easily be imagined if by any chance a vessel began to pitch in a seaway, with a very long hold only partially filled. Under such circumstances, for any bulkhead to bear the strain would be practically impossible, not to mention the additional danger which would arise from vastly increased change of trim and heavy diving which would undoubtedly ensue. Transverse bulkheads should therefore never be spaced at greater intervals than between 24 and 28 ft., and should be thoroughly oil- and water-tight. Vessels carrying liquid cargoes are especially subject to severe racking stresses, and strength to encounter such is largely provided by these numerous transverse bulkheads.

As before stated, all bulkheads, both transverse and longitudinal, should be very strong and well supported. Oil steamers should possess a reasonable metacentric height at every intermediate draught between the light and load lines, which is passed through as the tanks are being filled. In the fully loaded condition, from 1 to 2 ft. should prove a satisfactory metacentric height in vessels of usual proportions. No class of cargo vessel is so easy to manipulate in the process of designing, in order to arrive at a desired condition of stability, as the bulk oil-carrying steamer, because in no other cargo vessel is the seagoing condition so constant.

In order to provide for the increased bulk in the event of expansion taking place, a trunk-way is fitted in the 'tween decks continuously all fore and aft over the main hold tanks. This is shown clearly in fig. 78. The transverse bulkheads must extend to the top of the expansion trunk.

In order to minimise the danger of leakage, so as to prevent either oil or gas finding its way either into the engine and boiler space or cross bunkers, or into any hold space used for other purposes than carrying oil, double bulkheads are fitted at a distance of not less than two frame spaces apart. Both these bulkheads are oil-tight, and extend from side to side, and from the keel to the top of the expansion trunk. In fig. 76, where the engines and boilers are situated at the after end of the vessel, the two oil-tight bulkheads just mentioned are shown between the cross bunker at the fore end of the boiler room and the aftermost oil tank. The space between these

IDSHIPS.


Crew
Store
Store
Chain Locker
Water Ballast
Cofferdam
ompartments
Ballast T
S
Coffe
Reserve Bunker
Expansion Trunk
Oil Compartment

bulkheads is called a *coffer-dam.* In this vessel, as the whole compartment abaft of the collision bulkhead is used for general cargo, a coffer-dam is again found between this compartment and the foremost oil tank. It is most unusual to carry oil in the endmost compartments of any steamer. Indeed, for vessels passing through the Suez Canal, this is strictly enforced; and another regulation is that the coffer-dams be filled with water to their utmost extent, when carrying oil in bulk. This, it is hoped, will form an effective barrier against any oil finding its way through the coffer-dam. But even with these precautions, owing to bad riveting, or excessive straining of the bulkheads arising from defective stiffening, oil and gas have been known to percolate through the coffer-dam bulkheads into cross bunkers and into engine and boiler rooms. When this has happened in vessels where it has been customary to fill the coffer-dams with water, this serious condition of affairs has generally been brought about by part of the water leaking from the coffer-dam, its place having been taken by oil which has leaked into the coffer-dam and floated on the water, and eventually found its way into the adjoining spaces. Hence that these coffer-dams be frequently inspected during the voyage and their condition ascertained, is most essential. If oil is found in the space, it should be drawn off. Ample ventilation to the coffer-dams is extremely necessary. Some owners prefer to keep the coffer-dams empty, and by frequent inspection, the ships' officers are kept cognisant of their condition. In the event of oil having found its way into the space, it is immediately pumped back into the main tank. In this case again, thorough ventilation is essential. Fig. 79 shows an enlarged view of a coffer-dam in a vessel where the engines are situated amidships. It will be seen in the coffer-dam diagram that the strength of its two bulkheads is united and great additional support given by means of the diaphragm plates shown. In a transverse direction, these diaphragm plates are spaced about 3 ft. apart. In fig. 77, which shows the engines and boilers amidships, it will be observed that a coffer-dam is situated at the aft end of the engine room, another at the fore end of the cross bunker forward of the boiler room, another at the fore end of the foremost tank, and another at the after end of the aftermost tank. While there is much to be said in favour of placing the engines and boilers amidships, the great advantage of placing them at the after end is that they are more entirely shut off from the oil tanks, and the danger rising from leakage minimised. To ensure safety, the donkey boiler and galley must be thoroughly isolated from the oil tanks.

The transverse frames should preferably be of bulb angle, or channel, or Z bars, instead of the ordinary frame and reverse bars. This reduces the riveting and secures greater transverse strength, which is a highly important factor in bulk oil-carrying vessels. In two decked vessels, the second deck forms the crown of the main oil tanks. It should therefore be a thoroughly oil-tight flat. To secure this most effectively, all the frames are usually cut in way of this deck, and the deck plating carried without a break right out to the shell of the vessel, to which it is connected by a continuous angle bar. This is clearly shown in the midship section, fig. 78. The frames in the

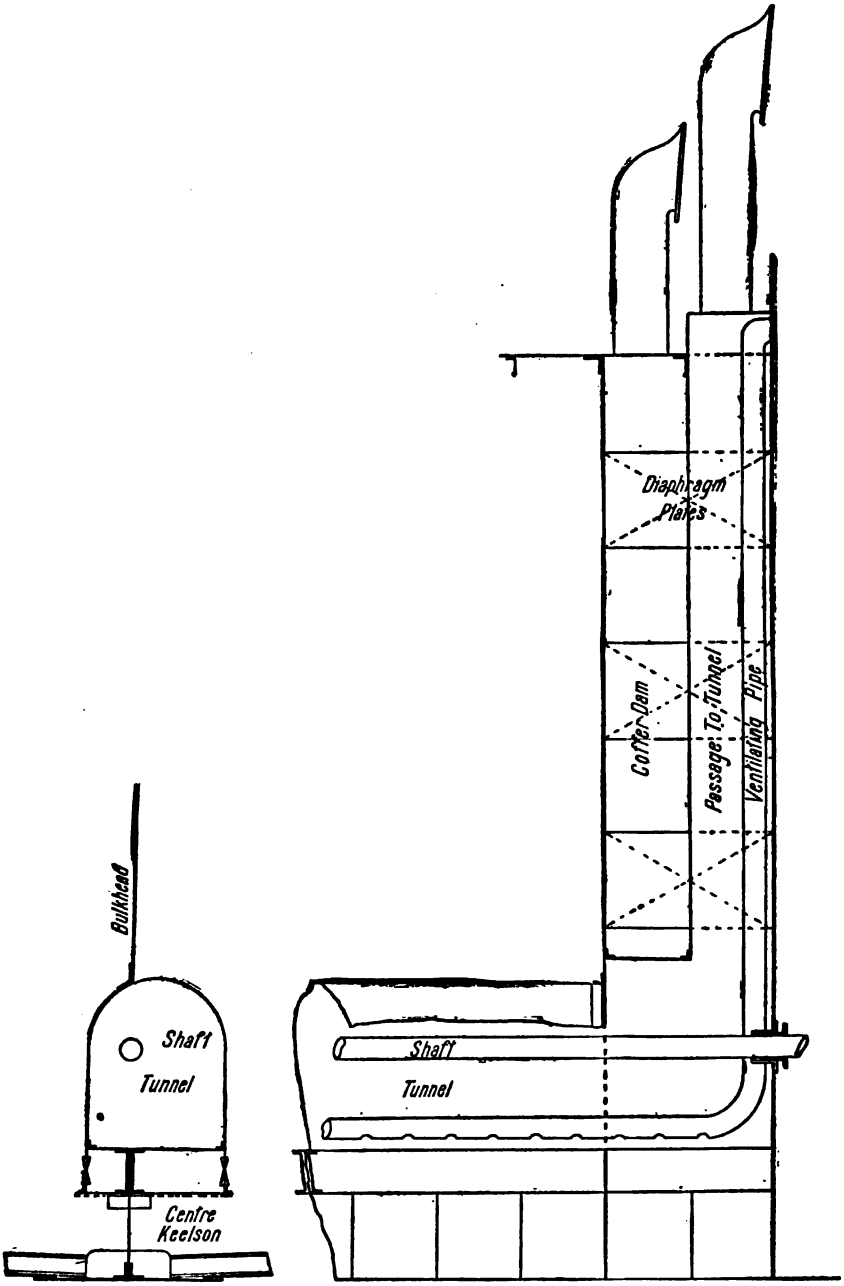

Diaphragm Plates
Coffer Dam
Passage To Tunnel
Ventilating Pipe
Bulkhead
Shaft
Tunnel
Centre Keelson
Shaft
Tunnel

FIG. 79.—Enlarged View of Coffer-dam, showing Diaphragm Plates, Trunk-way to Tunnel, and Ventilating Pipe.

FIG. 78.

'tween decks are connected to the beams at their upper extremity, and to the deck at the lower extremity, by means of bracket knees. The expansion trunk (see fig. 78) is fitted all fore and aft in the 'tween decks, and its sides are supported by webs of plating at intervals as shown. All the oil hatches on the upper deck must be strongly constructed and oil-tight. The spaces in the 'tween decks at the sides of the expansion tanks are used as bunkers. The plan of the upper deck (fig. 76) shows the arrangement of all the oil and bunker hatches, and the plan of the second deck (fig. 76) shows the continuous expansion trunk-way, and the longitudinal and transverse bulkheads, including the coffer-dam bulkheads. Where lines indicating bulkheads are shown in full, they extend to the upper deck; and where such parts of them are dotted, they terminate at the second deck.

In oil vessels of a depth such as to require three tiers of beams, the lower deck is usually dispensed with as shown in the midship section, fig. 78, compensation being made by means of web frames and web stringers. Two web frames are usually placed in each oil tank. An extra deep beam extends across the vessel at the head of each web frame, to which it is connected by a large plate knee, as dotted upon the midship section. The longitudinal bulkhead, which is oil-tight, extends from the keel plate to the top of the expansion trunk. The vertical stiffeners are of bulb angles one frame space apart, lapped on to the floor plates, and further connected to the floors and to a narrow width of deck plating through the expansion trunks by plate brackets. At intervals, deep web plate stiffeners are fitted. These are spaced to agree with the web frames on the ship's side, the bulkhead web plate stiffeners being bracketed to the deep plate beams which unite the heads of the web frames. They are also lapped on to and bracketed to the floor plates (see fig. 78). On the other side of the longitudinal bulkhead, channel plate horizontal stiffeners are fitted, spaced so as to be at the same distances above the keel as the web stringer plates.

The transverse bulkheads are continuous from side to side of the vessel. The longitudinal bulkheads are therefore fitted intercostally, as it were, between them.

The stiffening of the transverse bulkheads is very similar to that just described for the longitudinal bulkhead. (See figs. 80 and 81.) The vertical stiffeners, which are of bulb angles, are spaced about 2 ft. apart, and the horizontal channel plate stiffeners agree with the spacing of the web stringers and horizontal stiffeners in the longitudinal bulkhead.

The vertical stiffeners are bracketed, top and bottom, as shown in figs. 80 and 81, and the horizontal stiffeners of both the transverse and longitudinal bulkheads are thoroughly united by large brackets as shown in fig. 81.

Transverse bulkheads, exceeding 42 ft. in breadth, should have four vertical web plate stiffeners in addition to the longitudinal bulkhead, and where the breadth is less, two vertical webs, one on each side of the longitudinal bulkhead.

Attention is drawn to the splendid stiffening which is afforded to the oil tanks in the arrangement just described by having all horizontal stiffeners and web stringers practically in the same horizontal plane, each tank being circumscribed by this web system of stiffening.

As the oil-tightness, particularly of the transverse bulkheads, is of such paramount importance, it is usual to cut all stringers and keelsons which would pass through this bulkhead, and preserve the continuity of strength of these important longitudinal girders by large bracket plates, as shown in fig. 82. Sometimes, however, the side stringers are carried uninterruptedly through the transverse bulkheads, as in fig. 81. In this case, most efficient angle collars have to be fitted metal to metal to preserve watertightness.

The connection of all seams and butts in the plating of bulkheads should be by means of laps, double riveted throughout. A most important point in all oil-tight work is to avoid three-ply riveting, as the tightness of such is not nearly so reliable. Thus, that the connection of the transverse bulkheads to the shell plating and deck and to the longitudinal bulkheads be by means of large single angle bars, with flanges broad enough to take two rows of zigzag riveting, is strongly recommended. (See figs. 80, 81, 82, 83, and 84.)

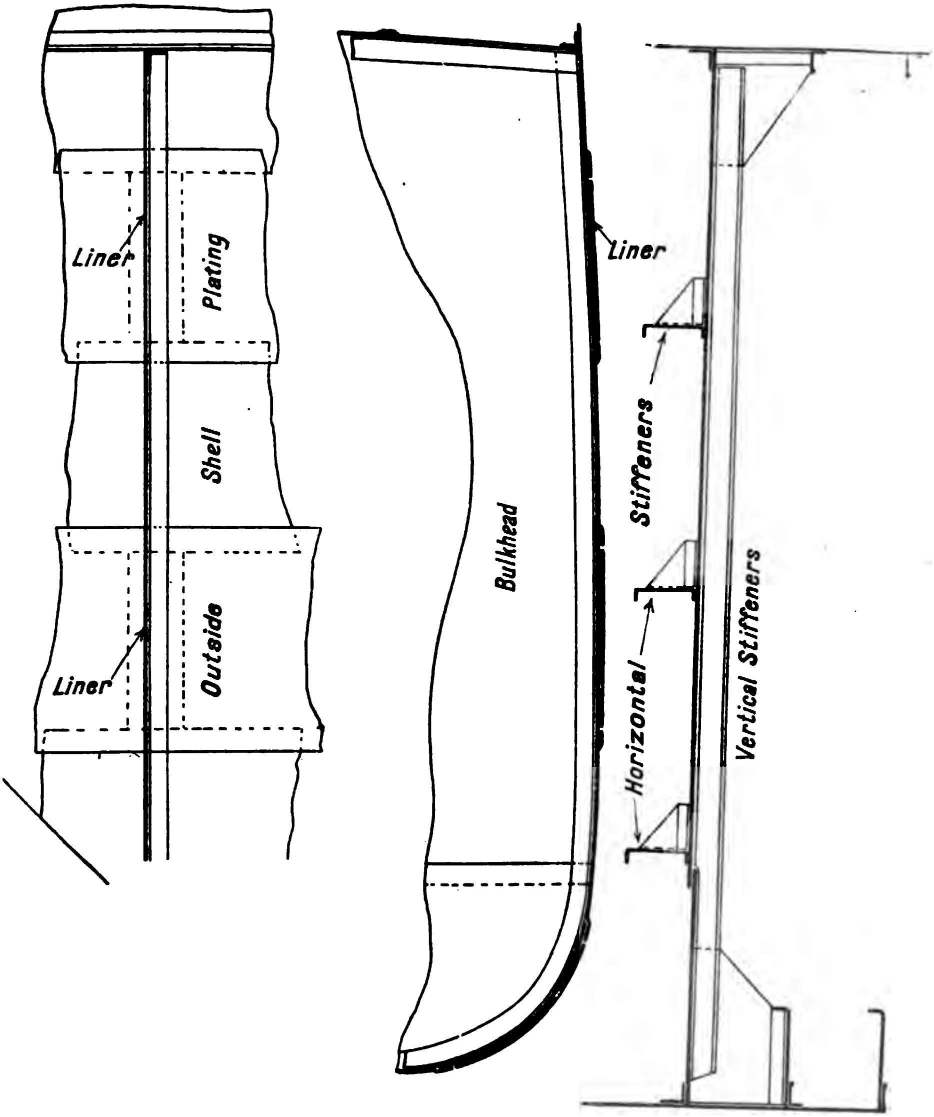
The bulkhead liners fitted to alternate strakes of shell plating are usually of sufficient width, so as to get one row of rivets on each side of the bulkhead shell bar. This, it is found, is more easily caulked and made watertight. (See fig. 84.) When the shell plating is flanged, as shown in the midship section, fig. 78, each strake of shell plating therefore bearing close upon the frames, and no packing being required, the bulkhead liners may be fitted on the outside of alternate strakes of the shell plating (see fig. 80), but more usually the liners are dispensed with, and by making the bulkhead shell bar of extra thickness, a wider spacing of shell rivets is obtained, so as to weaken the shell as little as possible.

That the bulkheads be caulked upon both sides is strongly recommended. In order to ensure thorough tightness at all connections, this should be secured by the surfaces of the metal bearing hard upon each other. Felt packing should, under all circumstances, be avoided in oil-tight work, and white lead as far as possible. The latter, however, cannot always be entirely dispensed with, white lead injections being at times necessary.

The seams of the shell strakes should be double riveted, and the butts preferably overlapped and treble riveted with three complete rows of rivets. Two rivets should pass through the seams upon every frame instead of the single rivet in ordinary cargo steamers, in order to ensure oil-tightness. If the butts are not lapped, they should be connected by double butt straps treble riveted in way of all oil-tanks. When the engines are situated amidships, as in fig. 77, the shaft tunnel is entered by

FIG. 80.

TRANSVERSE BULKHEADS.


Liner
Plating
Shell
Outside
Liner
Bulkhead
Liner
Stiffeners
Horizontal
Vertical Stiffeners

means of an oil-tight trunk-way from the upper deck at each end of the tunnel. In fig. 77 this trunk-way passes through the coffer-dam at each end of the tunnel and is itself independently oil-tight. An enlarged view of the fore trunk-way is shown in fig. 79. Needless to say, the tunnel

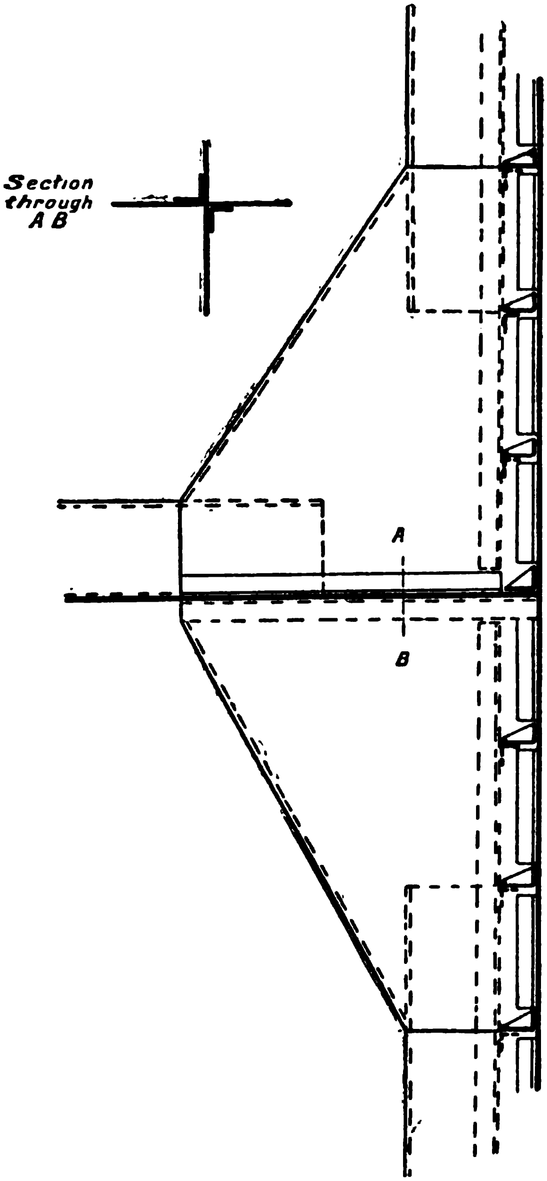


FIG. 82.—Showing a Side Stringer cut and bracketed to a Bulkhead (oil steamer.)

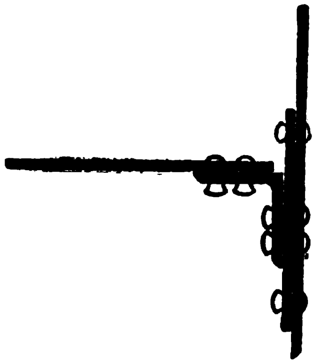


FIG. 83.—Showing Bulkhead Liner and Angle Connection to Shell.

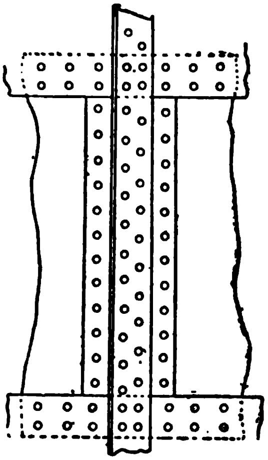


FIG. 84.—Bulkhead Liner.

is thoroughly oil- and gas-tight. It should, however, be well ventilated by cowl ventilators into each trunk-way.

The gases which are emitted from the oil are of greater specific gravity than the atmosphere; they are, therefore, apt to lodge about the lowermost recesses of all spaces into which they enter. A system of drawing off any such gases, and assisting in the ventilation of the tunnel, is shown in fig. 79, where a large perforated pipe passes along the tunnel and up the trunk-way to a fan which acts as a suction.

Even when all the oil has been pumped out of the oil tanks, great danger still exists for the reason just mentioned, viz., that the heavy and inflammable gases hang about the bottom of these spaces. To rid the tanks of these objectionable and dangerous vapours, several means are used, the chief being to blow out the gases by means of steam injections, and to draw off the gases by using the oil suction pipes with a fan. Steam injections are sometimes used when necessary in the tunnel. Ample ventilation should be provided to all oil tanks. In order that the oil may readily reach the pump suctions, sufficient limber holes should be fitted through floors and side intercostal plates, but on no account through the middle line bulkhead.

Oil vessels have been built with an inner skin, but there is little to recommend this system, the space between the inner and outer skins being a harbourage for gas. When such a system is adopted, the importance of fully ventilating these spaces is obvious.

Water-ballast Arrangements.

It is not intended in this chapter to enumerate and discuss the reasons and necessity for arrangements in the modern cargo steamer for the carriage of water for ballasting purposes. This has already been done in "Know Your Own Ship." Suffice it to say, as every seaman knows, that in these days of fluctuating freights, large vessels frequently make long over-sea voyages without cargo. And with the full bilge and small rise of floor so commonly given to present-day steamers, and remembering, too, the great increase which has taken place in the dimensions of such vessels, it follows that the draught in light condition is greatly less in proportion than it used to be for the finer formed and smaller-sized cargo vessels then in use. All this enhances the necessity for ballast when in a light condition, and as water has been found to be the most economical ballast that can be carried in steamers, it is proposed to illustrate the principal arrangements for the carriage of water-ballast.

M'Intyre Double Bottom Tanks.—The first occasions upon which water-ballast was introduced into vessels were to enable colliers carrying coal from the Tyne to London to make the return voyage without the necessity and expense of loading, and at the end of the return voyage discharging dry ballast. The necessary alterations in the first vessels fitted for this purpose were carried out by Messrs. Palmer & Co., of Jarrow-on-Tyne. In the system then adopted, the water ballast was carried along the bottom and contained between the outer and an inner bottom, which latter was laid upon fore and aft girders standing upon the ordinary floors, and made watertight by being connected to the outside plating.* Fig. 71 illustrates the midship section of a vessel fitted with the modern arrangement of such a double bottom tank, in some of the smaller details the construction having been slightly modified from what it was originally. For instance, in some of the earlier cases, the tank top plating was carried in a horizontal, or almost horizontal direction from the top of the centre keelson right out to the bilge or shell plating, and made watertight at each of its side extremities by being connected to the shell by means of angle collars. Another system of making this connection is by flanging the tank side or margin plate similarly to the system illustrated in fig. 71, so as to meet the bilge plating at right angles. The watertightness is here again secured, and the connection made by means of angle collars. In both of these cases the reverse frames are cut at the tank side, and compensation made by doubling the frame bar (which is continuous from keel to gunwale) for about 3 ft. This greatly facilitates the fitting of the watertight collars.

But the method now most usually adopted for the connection of the tank side to the shell plating is that shown in fig. 71, where the tank side or margin plate is arranged to meet the shell at right angles. In this case the main frames are cut at the tank side and the margin plate is connected to the shell by a continuous angle bar. This is probably the simplest way of ensuring the watertightness of the tank. The efficiency and continuity of the transverse framing is effected by connecting the frame legs outside the tank to the tank side plating by means of large bracket plates or tank knees. Hence the tank side plate must have sufficient breadth, so as to get a sufficient number of rivets through to ensure a good connection.

Cellular Double-Bottom Tanks.—However, since the inauguration of the M'Intyre tank, a very considerable development has taken place, and now a type of tank which is more embodied in the main hull of the vessel has come to be extensively adopted, though not to entirely supersede the M'Intyre tank. This tank is that illustrated in figs. 12, 48, and 58, and is known as the cellular double-bottom water-ballast tank. In the M'Intyre double-bottom tank the floors are upon every frame all fore and aft, and in the earliest form of this tank the ends of the floors were turned up the bilge in the usual way. But in later M'Intyre tanks, the floors inside the tank have been carried in a horizontal line from the centre keelson to the intersection with the frame or tank side, and strengthened at their narrow outward ends by bracket plates fitted to the tank side. (See fig. 71.) If desired, this tank may extend over only part of the length of the vessel, the remainder of the bottom being of the usual construction. The tank is commonly dispensed with under the engines, and especially under the boilers, on account of the rapid corrosion, due to damp heat, which is known to take place under the boilers.

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* This is known as the M'Intyre tank, as the idea originated with Mr. John M'Intyre, the manager at that time of Palmer's shipyard.

In the cellular double-bottom form of construction, the centre keelson or the centre through-plate is continuous fore and aft, with two large continuous angles on its upper and lower edges. The floors in mercantile steamers are usually solid from the centre through-plate to the tank margin plate, lightened by manholes as shown in figs. 12, 48, and 58, which manholes are also the only means of passage through the tank. The inner bottom plating is laid on the top of these floors, and the margin plate is arranged at the tank side so as to meet the shell plating practically at right angles. The floor plates are stiffened and prevented from buckling by fitting one or more intercostal girders, according to the size of the vessel, which are connected to the inner and outer bottom plating and to the floor plates by angle bars. (See fig. 48.) Or the angles taking the inner and outer bottom may be dispensed with by flanging the plates (See fig. 64.)

Where, however, the maximum longitudinal strength is desired, these side girders are commonly fitted continuous all fore and aft, the floor plates and reverse bars inside the tank between them, therefore, being intercostal owing to the top angles on the side girders being continuous. On account of the depth and strength of the floor plates, the large frame bar, such as is fitted outside the tank, is not required, and, as shown in fig. 48, a smaller bar, whose flanges are of about the size of the smaller flange of the ordinary frame, is used. As shown in fig. 48, the reverse bar is fitted, as in the case of ordinary floors, on the opposite side of the floor plate to the frame bar. The tank side is made watertight by fitting a continuous bar on the lower outside edge of the margin plate, so as to bear hard against the bilge shell plating to which it is riveted. Both frames and reverse bars are severed at the tank side, this being necessary in order to simplify the rendering of the inner bottom watertight. However, as the transverse strength must be uninterruptedly maintained, the frame legs are attached to the tank side by large bracket plates carried well up the bilge. These are connected to the tank side by double angle bars for at least half the length in large vessels. It may be noted that the reverse bars in the double bottom are doubled under the engines and boilers where special rigidity is required, and for the same reason, additional intercostal side girders are fitted. The cellular double-bottom ballast tank is usually divided into numerous separate watertight compartments, not only for the purpose of subdivision in the event of the perforation of the outside plating, but in order to ballast the vessel so as to obtain a desired condition of trim.

Fig. 85 shows a modification in the construction of the cellular double-bottom tank, as previously shown.

In this system, the longitudinal side girders are more numerous, and the floor plates are only solid upon alternate frames. On the intermediate frames, brackets are fitted to the centre through-plate and the tank side. The connection of the tank side to the frame legs is identical with that previously described for the more ordinary cellular double bottom, brackets being fitted to every frame. A point to be noted in this form of construction is, that whereas in Board of Trade *standard* vessels with cellular double bottoms having solid floors to every frame, when the shell plating in way of the double bottom is $\frac{11}{20}$ths or more in thickness, a reduction of $\frac{1}{20}$th is permitted; no such reduction is allowed where the floors are not solid upon every frame. All double-bottom tanks are entered by means of manholes in the tank top plating, which should be sufficiently numerous and situated in such positions as will give the easiest access to every cell or compartment in the tank. At least one manhole should therefore be cut in every solid floor plate between the longitudinal girders, whether intercostal or continuous, and, at intervals, manholes should be cut in the side girders also; but as the centre through-plate is a most important item in the longitudinal strength of the vessel, upon no account should it be perforated by manholes, as this would seriously interrupt the continuity of its strength. Indeed, in some vessels the centre through-plate is perfectly watertight, for part, if not for its whole length.

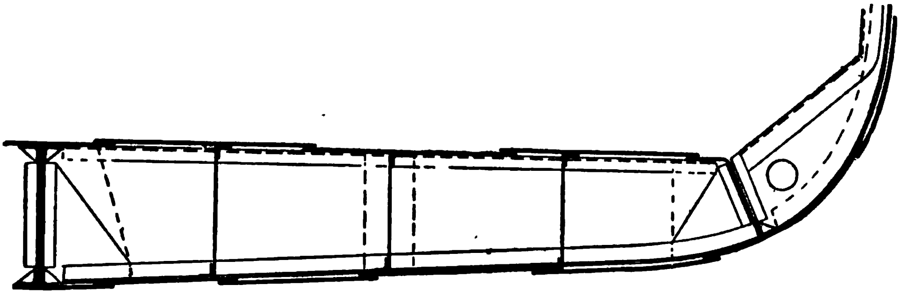


FIG. 85.—Cellular Double Bottom, constructed with Solid Floors upon alternate frames, and Bracket Plates upon intermediate frames, as shown in this sketch.

Fore and After Peak Tanks (see figs. 46, 47, and 49).—As the lower spaces on the fore side of the collision bulkhead, and on the after side or the aftermost bulkhead, are both inconvenient and unsuited for the carriage of cargo, and ill adapted even for ship stores, it has become common in steamers to use one or both of these spaces in which to carry water for trimming purposes. It is scarcely correct to call them ballast tanks, for their capacity is comparatively so small that the weight of water they contain produces very slight increase in the mean draught, but the filling of one of them produces considerable change in the trim, situated as they are so far from the centre of gravity of the ship. Hence, in a light condition, the filling of the after-peak rank may considerably contribute to the immersion of the propeller, though there follows the natural objectionable result of the bow being lifted correspondingly out of the water. The fact must not be overlooked, that when these tanks are made very large, containing, as they do in some cases, over 100 tons of water, they are liable to produce straining when the ship pitches in a seaway in the light condition. In any case, the bulkhead separating these tanks from the holds will be watertight, though, when the peaks are intended for water-ballast, these bulkheads should be especially strengthened. In addition, the deck forming the top of such a tank must also be watertight. It must therefore be constructed of iron or steel, and if the space complies with the conditions necessary for its exemption from the British tonnage, it must be entered only by means of a manhole in the deck plating. As there is always the danger of these tanks being only partially filled (a condition which ought to be rigorously striven against), wash plates are fitted down the middle of their length. (See fig. 49.)

Deep Midship Tanks.—Especially in recent years has the practice been adopted of constructing one or more deep water-ballast tanks, somewhere in the middle length of the vessel, usually at one or both ends of the engine and boiler space. Fig. 72 illustrates the position of these tanks. They are in reality hold spaces so constructed as to be available for the carriage of cargo when required, and water as ballast when in a light condition. They are bounded on each end by watertight bulkheads specially strengthened, and are enclosed on the top by a watertight iron and steel deck or flat. When these tanks extend from side to side of the vessel, a watertight bulkhead must be fitted down the middle of the tank in a fore and aft direction. These tanks are entered by means of small hatchways through the watertight deck, which hatchways are themselves made watertight by means of an iron or steel plate bolted on to their coamings. The steamer in fig. 49 has a deep water-ballast tank at the after end of the engine room.

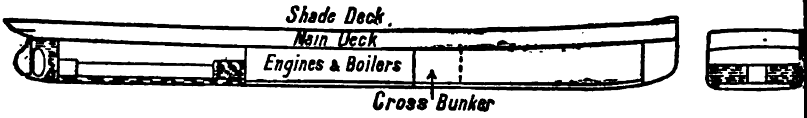
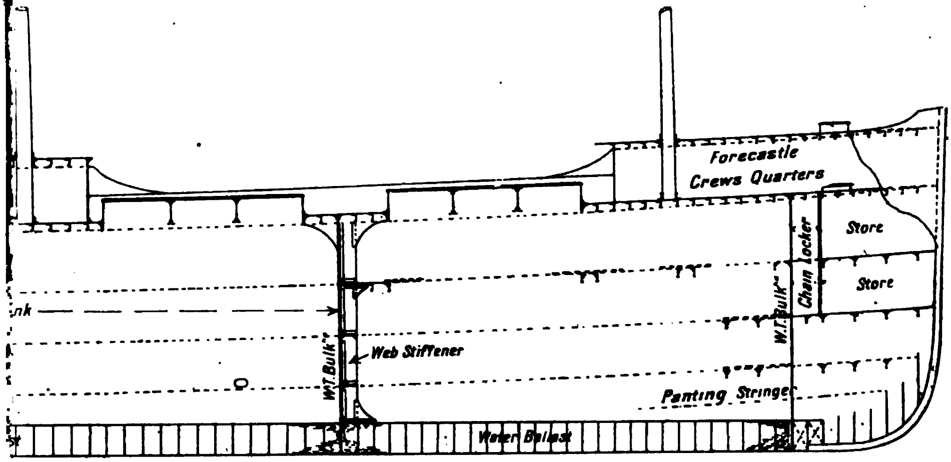
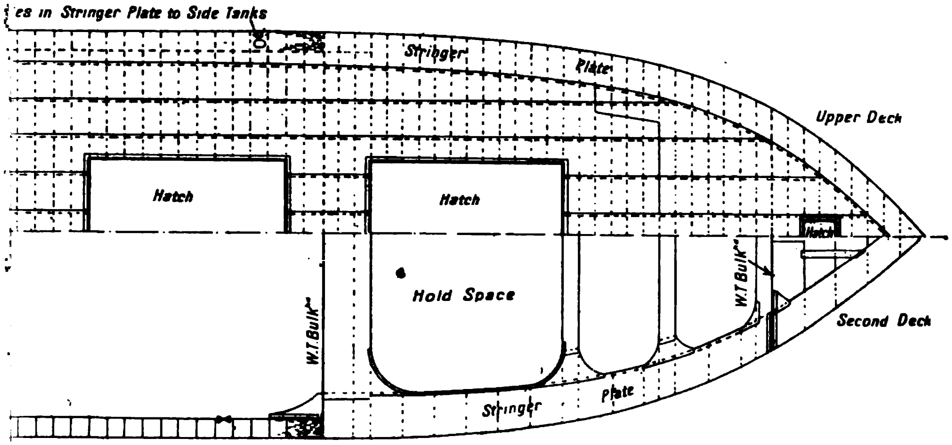


Fig. 86.—Illustrating Side Water-ballast Tanks in shallow high-speed Passenger Steamers.

Side Deep Tanks.—Instead of carrying midship deep tanks from side to side of the vessel, they are sometimes fitted only in the wings. (See fig. 86.) Carrying less water than they would do if fitted from side to side, they do not produce as much increase of immersion, but from a theoretical point of view, they possess a decided advantage in easing the vessel in her rolling motions, and producing a steadier ship. They are therefore better adapted for shallow high-speed passenger vessels, which carry little or no cargo. In such cases, an ordinary manhole is sufficient as a means of entrance, but

LLAST TANKS.


Forecastle
Crews Quarters
Store
Store
Chain Locker
W.T.Bulk'd
nk
Web Stiffener
W.T.Bulk'd
Panting Stringer
Water Ballast


es in Stringer Plate to Side Tanks
Stringer
Plate
Upper Deck
Hatch
Hatch
Hatch
Hold Space
W.T.Bulk'd
W.T.Bulk'd
Second Deck
Stringer
Plate

where it is desired to use these tanks for other purposes than water-ballast,—bunker coal, stores, or cargo,—watertight hatches may be fitted.

M'Glashan's Patent Ballast System.—The inventor of this system of ballasting, realizing the unsuitability of the ordinary double bottom tank as a sole means of ballasting, has devised the system illustrated in figs. 87, 88, and 89, whereby, in addition to a cellular double bottom which is of the ordinary mode of construction, side tanks are built into the vessel's structure on the sides over the middle length. The extent and construction of these tanks are fully illustrated in the profile, midship section, and deck plans, together with the notes given upon the same, in figs. 87, 88, and 89.

In the vessel we illustrate, the side tanks extend from the cellular double-bottom tank margin plate to the upper deck. The breadth of each side tank is about 27 in., and they extend in a fore and aft direction over at least one-half the vessel's length amidships. The framing in the way of these tanks is somewhat similar to the web frame system, solid plate web frames, lightened by manholes, being fitted to the alternate frames. The longitudinal framing on the vessel's sides is composed of web stringer plates fitted intercostally between the web frames. The upper deck beam knees are riveted to the inside tank plating by means of angle bars. In addition to the increased and improved facility for the carriage of water-ballast in this vessel, several other advantages are gained.

1st. Over the midship half length, the vessel possesses an inner skin from gunwale to gunwale. This may prove of immense value to the safety of the ship in the event of the outer skin being perforated, owing to collision or other cause.

2nd. The additional strength which is manifestly given to the structure by two vertical skins of plating on each side, supported and united as they are by the transverse and longitudinal web framing, fully compensates for the omission of the lower deck beams in the way of these tanks. This, in its turn, improves the conditions for stowage of cargo. The capacity of the hold space is somewhat reduced, but it should be remembered that the tonnage also suffers reduction, as it is only measured to the inner tank side plating, and it is also noteworthy that a vessel built on the ordinary web frame system suffers from broken stowage of cargo, owing to the web framing, which projects 15 or 18 in. from the shell plating into the hold. The construction of the vessel forward and abaft of the side tanks is of the usual kind. A most important point in such tanks as these is that free access be readily gained to every part of the interior, hence manholes fitted with watertight plate covers are cut at intervals through the deck plating. (See plan, fig. 88.) And in order that access may be obtained from the hold or machinery space, manholes with similar watertight covers are cut through the inner tank side plating. In addition, as previously pointed out, the transverse web plates are lightened by numerous manholes which facilitate the means of passage from one part of the tank to another, and the longitudinal web stringers also have manholes cut through them for a similar reason. This is absolutely essential in order that the tanks may be frequently, and as easily as possible, examined inside, and measures taken for their maintenance. In other respects, these vessels are similar to an ordinary cargo or passenger steamer.

The foregoing are the principal arrangements for water-ballast in use at the present day.

CHAPTER VII.

DETAILS OF CONSTRUCTION.

Rivets and Riveting—Butt Straps and Butt Laps—Keel Blocks and Launching Ways—Frames, Reverse Frames, and Floors—Beams—Pillars—Keelsons and Stringers—Bulkheads—Decks—Outside Shell Plating—Stern Frames and Rudders—Miscellaneous Details: Continuity of Strength, Engine and Boiler Space, Masts and Derricks, Panting, Hatches, Deck Houses, Poop and Bridge Front Bulkheads, Tunnel and Casings, Breast Hooks, Bilge Keels—Ventilation—Pumping—Launching.

Rivets and Riveting.

Quality of Riveting.—However carefully and perfectly the ship designer may determine the scantlings and arrange the material for the construction of a vessel, and however excellent may be the quality of the material, unless the innumerable plates and bars which go to make up the whole hull are most efficiently united to one another, it is impossible for the structure to develop its full strength without fracture at some of the most heavily strained connections supervening. Thus, while thoroughly efficient butt and edge connections should be arranged for in so far as this is obtained by the amount of overlap or size of straps and number and diameter of rivets, everything depends entirely upon the quality of the riveting. Bad riveting utterly frustrates all ingenuity displayed in the design. In short, good workmanship is of the very highest importance in shipbuilding, and too great a stress cannot be laid upon this feature. Bad riveting has put many a shipowner to enormous expense, owing to the delay and cost of effecting repairs, and it is not altogether new to hear of huge ocean liners being put into dry dock in order to have their shell plating partially or entirely re-riveted. Carelessness in marking off and spacing rivet holes, and also in the operation of punching, invariably produces what are known as *blind* holes. These occur where the rivet holes, in overlapping plates or bars, are only partially over one another. A most objectionable practice under such circumstances is to force a passage for the rivet by means of a drift punch. Such a method should be rigorously forbidden. The proper way in which to clear away any obstruction caused by blindness should be by means of a rimer (a drill).

The tightness of rivets is tested by tapping the side of the rivet head with a small hammer, while two fingers of the other hand rest against the opposite side of the rivet head. An experienced workman can immediately detect a loose rivet. Loose rivets should never be caulked tight, but renewed and re-riveted. Sometimes, in testing a tank, or a water- or oil-tight compartment, a tight rivet may show signs of leakage; the only rivet which under such circumstances admits of being satisfactorily caulked watertight is the plug-head rivet, all others should be re-riveted. It is always more difficult to obtain tight work where the riveting is more than two-ply. Thus, as far as practicable, two-ply riveting should not be exceeded.

A number of different forms of rivets are used in the work of shipbuilding for watertight or oil-tight work. Rivets Nos. 6, 5, and 3 in fig. 90 cannot be surpassed for general efficiency. Nos. 6 and 5 are known as pan-head rivets, and No. 3 as the plug-head rivet. Pan-head rivets with snap points (No. 4) are not so reliable for watertight work.

Pan-head Rivets.—It will be observed that the pan-head rivet is of conical form just under the head, or, to use the common phrase, it has a swelled neck. The reason for this is that when a plate or bar is being punched by a punching machine, the hole so punched is of conical form, increasing in diameter in the direction in which the punch passes, and as plates and bars are always punched from the faying surfaces (surfaces which have to lie against one another) the neck of the rivet is swelled so as to completely fill the hole in the plate or bar. In such places in the construction of the vessel where the work must be watertight, but the appearance of the rivet point is not of great importance, undoubtedly the best result can be obtained by beating down the point as shown in No. 6, fig. 90, especially if the rivet hole be countersunk.

A countersunk rivet hole is one which has more taper than is produced simply by punching. It is formed by taking the punched plate or bar to a machine with a countersinking drill, which gives the bevel required.

In some parts of the ship structure, however, it is necessary that the rivet point be as near flush as possible with the plating, as, for instance, in the outside shell plating, steel or iron decks, and top of double-bottom tanks. In such cases, the rivet holes must be well countersunk and the rivets beaten down, any surplus material in the rivet being chipped off, and the point finally beaten so as to present a slightly full or concave appearance. This is shown in Nos. 2, 3, and 5, fig. 90. The pan-head rivet with the swollen neck and countersunk point can be highly recommended for great holding power. The heads are laid up with facility, while the rivets themselves are well adapted for entirely filling the holes. When the riveting has been satisfactorily performed, reliable water- or oil-tight results are assured.

Plug-head Rivets.—Plug-head rivets are also capable of producing highly satisfactory oil- or water-tight work, though greater care is requisite in performing the riveting. As shown in No. 3, fig. 90, the head of this rivet is of conical form, and it is intended to fill a rivet hole which has been countersunk. In laying up the rivet head, though the hole should be completely filled, the rivet head must project at least $\frac{3}{16}$ths or $\frac{1}{4}$th of an inch beyond the plate.

When this rivet has failed, it has generally been brought about by allowing too little projection, with the result that when heavy stresses have been experienced, the rivet head has not possessed sufficient holding power, and it has been torn through the rivet hole. However, where care is exercised, and rivets with insufficient head projection are condemned and renewed, excellent results are obtained. It is evident that this rivet is more successful where the thicknesses of the plates or bars which it connects are considerable, as it depends for its holding power very largely upon the depth of the countersinking. Where the material connected is thin, the pan-head rivet is preferable. The point of the plug-head rivet may be formed similarly to the methods described for the point of the pan-head rivet. Pan-head rivets have been used in

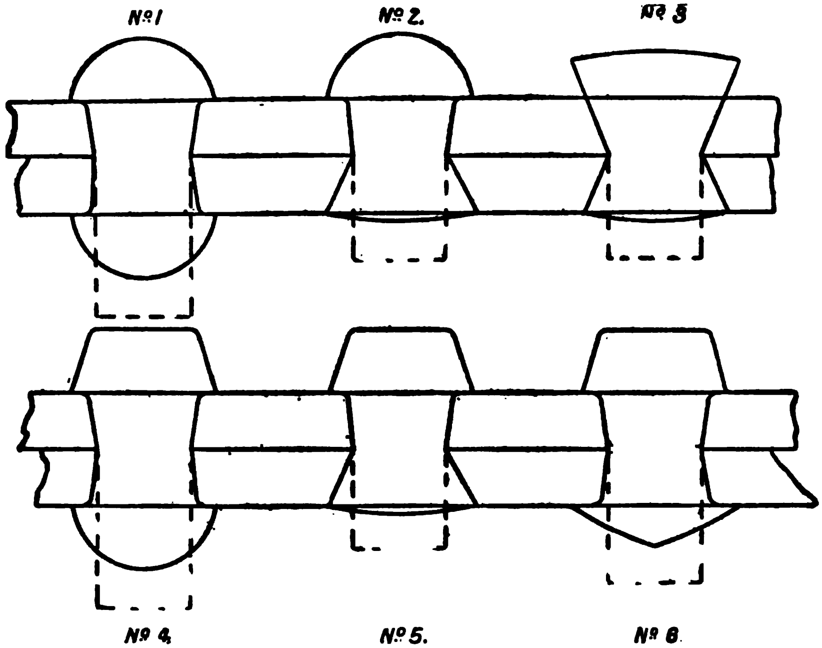


FIG. 90.—Forms of Rivets.

practically every part of iron and steel ships. The plug-head rivet has found special favour for the inner bottom plating of double-bottom tanks, certain parts of the shell plating, oil- and water-tight bulkheads.

Snap-head Rivets.—Another form of rivet used is that known as the snap-head rivet. (See Nos. 1 and 2, fig. 90.) As the semi-spherical head is very neat in appearance, this rivet is usually adopted in such internal parts of the vessel as are exposed to view, and where it is desired to give a finished appearance, such as in engine-room bulkheads, engine and boiler casings, etc. It is preferable that the rivet neck be swelled as shown in Nos. 1 and 2, fig. 90, thus better filling the hole. The point of the rivet may be either beaten down, or finished off flush with the rivet hole well countersunk. Sometimes, however, to form the point like the head is desired. This is done by placing a snap cup over the heated rivet point, after it has been put into place, and hammering the same until the head is clenched, and the semi-spherical form obtained. When this work can be performed by machinery (hydraulic, etc.), satisfactory results are obtained. But where the riveting is done by hand, the results are not always efficient, the tendency being, in hammering the snap cup over the rivet point, to press the edges of the rivet close, and to leave a hollow all round under the newly-formed head. At first detection is not easy, as the riveting appears to be quite tight, but should water eventually find its way under the newly-formed rivet head, corrosion takes place round the edge of the rivet and in the plate upon which it bears, and the result is that in the course of time the rivet becomes loose. Owing to the uniform and enormous pressure obtained in machine riveting, the objectionable tendency just referred to does not exist. In any case, snap riveting is greatly inferior to that previously described for pan and plug-head rivets. As is apparent, it is much more difficult to lay up a snap rivet head, especially if performed by hand.

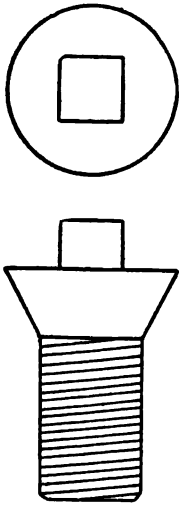
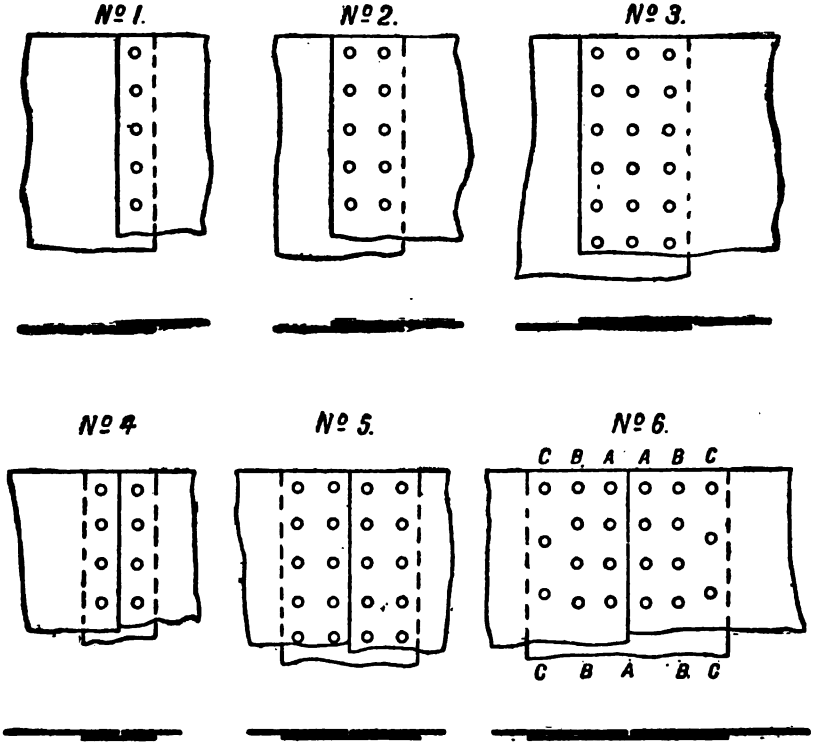


FIG. 91.
Tap Rivet. Plan of Rivet Head.

By laying up a rivet head is meant the operation of holding on to the rivet head by means of a heavy hammer, while the point is being beaten up and finished off, during which time the holder-on works his heavy hammer round the rivet head, thus thoroughly bringing it into close contact with the plate or bar.

Tap Rivets.—Another form of rivet used in ship work is the tap rivet. Its form is shown in fig. 91. It will be seen that it has a conical head with a thread turned upon the length of the rivet below. Upon the top of the head there is a rectangular projection. This rivet is used in places where it is difficult to get to the back of the material being riveted, in order to hold on, and finish off the point; or where it is desired to connect a comparatively thin plate to a thick bar or forging (stern frame, stem, etc.). The outer plate is countersunk to receive the rivet head, while a thread is put upon the lower portion of the rivet hole. The rivet is screwed into this by means of a key, and when thoroughly closed up, the projection on the head is chipped off.

Butt Straps, Butt Laps, etc.—The connection between two plates end to end is made either by fitting single or double butt straps, or by overlapping the plates.



Single Riveted Butt Lap. Double Riveted. Butt Lap. Treble Riveted Butt Lap.

Single Riveted Butt Strap. Double Riveted Butt Strap. Treble Riveted Butt Strap.

Fig. 92.

Fig. 92 illustrates single, double, and treble riveted butt lap and butt strap connections.

Comparison of Butt Lap and Butt Strap Connection.—Rows or strakes of plating such as are found in the shell, decks, etc., are usually connected at their edges by overlapping the plates, excepting in the case of yachts where, for the sake of appearance, a flush, smooth surface is preferred. In all cases, however, the overlap connection, when there are sufficient rivets properly spaced, is more efficient than the single strap connection. An attempt has been made to illustrate this in fig. 93, A and B. In B is shown a double riveted single butt strap; in A, a double-riveted overlapped butt. Suppose, in each of these cases, a tensile stress is experienced. The direction of the line of stress will be that shown by the dotted line which passes in the direction of the strake of plating between the butts, and at the butts necessarily through the butt strap, which is the binding agent. In any case, when such a stress is borne, the tendency is that it should be exerted in a straight line, which means that the tendency is to bring the butt strap into the same plane as the strake of plating. This necessarily produces an amount of pressure varying with the degree of stress at the back of the butt, which, though thoroughly well caulked before these stresses are experienced, tends to press forward the plating at the butt, and open the butt (as illustrated in an exaggerated form, see D, fig. 93), and produce leakage. Such results have actually taken place in many vessels, especially in the shell plating at the bilge, and it has not infrequently happened that the only way in which this damage could be effectively repaired has been by fitting an extra butt strap on the outside. In this case, the stress divides itself between the two butt straps, producing a pressure upon each side of the butt which neutralizes itself and thereby causes deviation in the plating impossible. This also explains why, in many of the important structural parts of every large vessel (sheer strake, bilge plating, upper deck stringer plate, etc.), double straps are fitted. The advantage of an overlapped butt over a single-

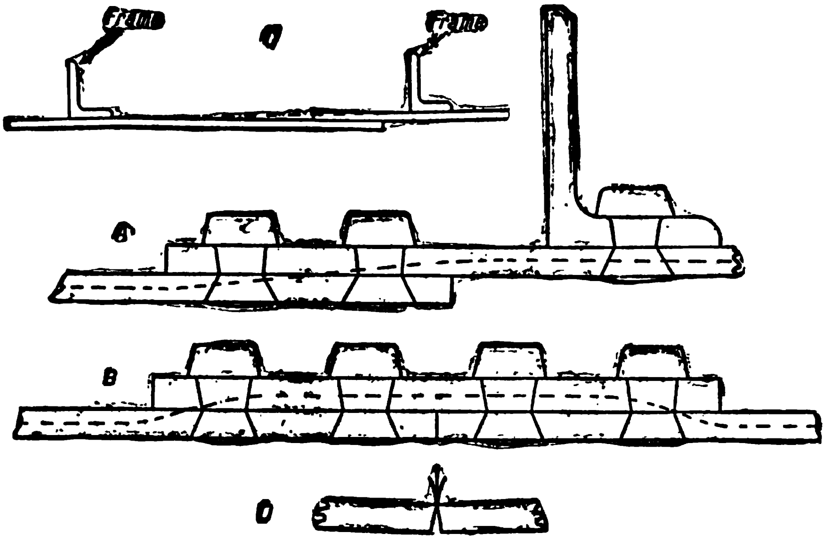


FIG. 93.—Butt Lap and Butt Strap connections.

strapped butt will be apparent on examining the butts in fig. 93. Here (A and C), though an equal amount of stress may have to be borne, no tendency to open or destroy the efficiency of the caulking exists. It may be noted, that under both tension and compression, the stress is borne by the rivets in the overlap butt, while, in the case of the strapped butt, the plate ends at the butt bear hard upon each other under compression, and the rivets are thus relieved of the stress, only being stressed under tension.

Strength of Butt Connections.—To observe a few of the considerations which must be kept in view in arranging the rivets in butt connections will be advisable at this point. Let fig. 94 represent part of the shell plating of an ordinary mercantile steamer whose butts are connected by means of single straps in the three upper strakes, and, for the sake of example, by butt laps in the three lower strakes of plating. In way of every frame, the shell plating must necessarily be perforated with a line of rivet holes round the whole girth from gunwale to gunwale, spaced according to the usual practice, 7 to 8 diameters of the rivet apart. Especially is it essential that no butts in adjacent strakes of the outside shell plating should come nearer to each other than at least two frame spaces, nor in alternate strakes than one frame space. This rule has therefore been observed in fig. 94.

Now, assuming that a severe shearing stress be experienced, and that the strakes of plating are composed of continuous material without any butts, it follows that rupture could only take place through one of the lines of frame rivet holes, say, through S S. But supposing the butt connection at Y Y to be exceedingly weak, the rupture would then most likely occur by shearing the plate through S X, and shearing all the rivets on one side of the butt strap, and so on down the line of the nearest frame rivets as shown. From this, it will be seen that to attempt to make the butt connection as strong as the unpunched plate would be absurd, for if such were possible, which obviously is not in the application of continuously increasing stress, as we have shown, the plating would ultimately shear through one of the lines of frame rivet holes. The efficiency, therefore, of the butt connection depends upon its strength relatively to that of the strake of plating in which it comes through a line of frame rivet holes.

The minimum shearing strength necessary for the rivets on one side of the butt Y Y should equal the strength of the plate through the line of nearest frame rivet holes, say, P P. Had the frame spacing been wider, or the butt straps only double riveted, there would have been one or more pairs of rivets in the seams between the frame and the edge of the butt strap. (See, for example, butt laps, fig. 94.) In such a case, before rupture could occur at the butt, not only would the rivets on one side of the butt have to be sheared, but these additional seam rivets also between the frame and the butt strap. The shearing strength of all the rivets on one side of the butt plus the additional seam rivets just referred to, should equal the shearing strength of the plate through the line of the nearest frame rivet holes, or in other words, the minimum shearing strength of the rivets on one side of the butt strap should equal the strength of the plate through the line of nearest frame rivet holes less the shearing strength of the additional seam rivets. Having arrived at the minimum number of rivets required for each side of the butt, they must now be disposed in such a manner as to produce no unduly weakened section in either the plate or the butt strap. A row of closely-spaced rivet holes, however, cannot be avoided on each side of the butt, A A, in fig. 94, this being necessary in order to ensure watertightness. The usual disposition of the rivets in treble riveted butt straps is shown in the three upper strakes in fig. 94, and also in fig. 92, No. 6.

There are five different ways in which fracture may occur at such connections. (See figs. 94 and 92, No. 6.)

(1) By the butt strap shearing through A A.

(2) By the plate shearing through C C.

(3) By the plate shearing through B B, and shearing the rivets in the row farthest from the butt, viz., C C.

(4) By the butt strap shearing through B B, and shearing all the rivets in the line A A.

(5) By all the rivets shearing on one side of the butt strap.

Were the row of rivets farthest from the butt spaced as they are in the other two rows, another particularly weak section would be created, for, as we have already stated, by the plate shearing through C C, total separation would occur. These rivets, however, are always more widely spaced. For moderately small vessels, Lloyd's require that every alternate rivet be omitted in the back row. For large vessels, however, a somewhat closer spacing is required, usually about 5 to 5½ diameters of the rivet from centre to centre. Were the butt strap of the same thickness as the plating, it is clear that by far the weakest section would be through the line A A, fracture of the butt strap through this line producing total severance of the plate. However, the necessary strength can be provided by increasing the thickness of the strap, and as a result the sectional area of the material through this line.

The tensile strength of the butt strap through the line of rivet holes A A should equal the strength of the plate through the line of rivet holes C C. The strength of a butt-strapped connection cannot exceed the strength of the plate through the line of rivet holes farthest from the butt.

Thus, classification societies demand one or several twentieths of an inch more thickness in the butt straps than in the plates they connect, over the vessel's midship length. For a similar reason, double butt straps should be each more than half the thickness of the plates they connect, while at the same time almost double the shearing strength is obtained in the rivets. When overlapped butts are adopted (see three lower strakes in fig. 94), the minimum shearing strength of the rivets is determined as previously described for the rivets on one side of the butt strap. As the rivets must be closely spaced in the row nearest to the caulking edge of the butt, no advantage whatever is gained by increasing the spacing of the rivets in the row farthest from the caulking edge, whether the butt be double or treble riveted, as the strength of an overlapped butt joint cannot exceed the strength of the plates through the line of rivet holes nearest to the caulking edge of the butt. In a deck stringer plate, the strength of the plate in way of a line of beam rivet holes regulates the minimum shearing strength of the rivets in a butt joint.

Classification Societies' Rules for Riveting.—While it is natural that every student of naval architecture should desire to possess an intelligent reason for the methods adopted in practice in ship construction, it may be pointed out that the registration societies give very full and complete information, not only as regards the scantlings of vessels classed with them, but also as regards the size, spacing, and number of rivets to be used in the various connections. And even in the case of vessels which are not classed with any registration society, the practice of the societies, at any rate in regard to the matter of riveting, is, as a rule, very closely followed. Indeed, that is a natural consequence, as Lloyd's Rules for the year 1885 is the standard upon which all British vessels are judged in being assigned a load line.

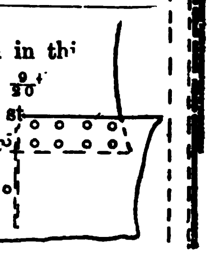
For the sake of illustration, we will notice some of the principal requirements of Lloyd's society.

A rule that should be observed in all rivet work is, that no rivet should come nearer to the edge of any plate or bar than its own diameter. In connecting two plates or two angle bars, or a plate and an angle bar in any important structural part, the greater thickness regulates the diameter of the rivet to be used. The corresponding diameters of rivets for plates or angles increasing in thickness is given in the adjoining table.

TABLE OF RIVETING.

Thickness of Plates in inches.	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{6\text{–}7}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{9\text{–}10}{20}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{12\text{–}13}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{14\text{–}15}{20}$	$\frac{15}{20}$	$\frac{16}{20}$
Diameter of Rivets in inches.	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1	1

When the outside shell plating is $\frac{7}{20}$ths of an inch in th
above from the keel to the upper turn of the bilge, and $\frac{9}{20}$
and above from the upper turn of the bilge to the sheer st
or landing edges of the strakes of plating are to be do
seam on the lower edge of the sheer strake must, in
riveted; for less thicknesses, the edges may be single
edge riveting, the space between the rows of rivets m



and a half their diameter. The distance between the centres of the rivets in a fore and aft direction should not exceed 4 to 4½ diameters.

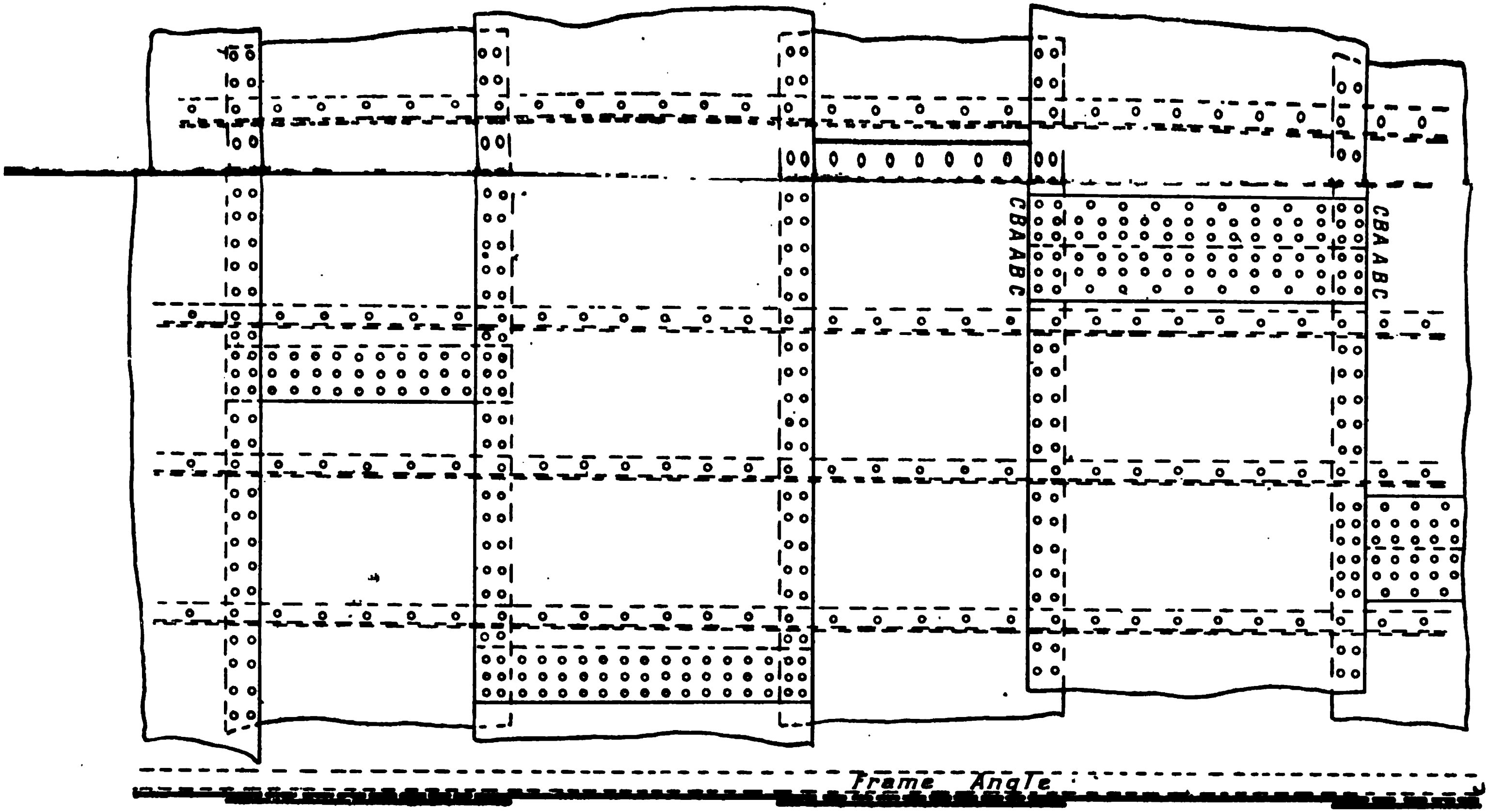
When the butts of the shell plating are overlapped, the butt must be treble riveted with three complete rows of rivets for at least one-half of the vessel's length amidships. When the 2nd numeral or the plating number is less than 16,000, the overlapped butts at the ends may be double riveted, but when above 16,000, the lap butts are to be treble riveted throughout.

Between each row of rivets in the butt there must be a space equal to twice the diameter of the rivet. In the other direction, the rivets in the butts must be not more than 3½ diameters apart from centre to centre.

When the shell butt connections are effected by means of butt straps, and the 2nd numeral is above 28,000, the whole of the butt straps all fore and aft are to be treble riveted. When above 24,000 and not exceeding 28,000, they are to be treble riveted for three-fourths the length amidships, and when above 20,000 and not exceeding 24,000, the butts are to be treble riveted for half the vessel's length amidships. Below 20,000, treble riveting is only adopted in the butts for the more important strakes of shell plating, such as the sheer strake, and one or more bilge strakes. In very small vessels the butts need only be double riveted. The rivets through the shell plating which take the frames are spaced from 7 to 8 diameters apart, and in order that the frame may not be unduly weakened, when the seams are double riveted by there being two rivets close together through the frames on every seam, one of these is omitted, the one left being the rivet nearest to the caulking edge. (See fig. 94.)

The butts of deck stringer plates should be at least double riveted, whether they be strapped or overlapped. As vessels increase in size, it becomes necessary to treble rivet the butts, and even to fit double butt straps. The spacing of the rivets in the butts is similar to that previously given for shell butts. The butts of a steel deck are to be double riveted for half the vessel's length amidships, and the seams to be single riveted 4 to 4½ diameters apart. The rivets connecting a steel deck to the beams are spaced 7 to 8 diameters apart.

In inner bottom plating, the butts and edges of the middle line strake all fore and aft, and also the butts of the inner bottom plating in the engine and boiler space, should in all cases be double riveted. Elsewhere, here the 2nd numeral is 20,000 and under 30,000, the butts of the inner plating should be double riveted for half the vessel's length In larger vessels it becomes necessary to double rivet both for at least half the vessel's length. The butts of outside ating, inner bottom plating, are chain riveted. In bar and stern frames, double zigzag riveting should be els. Rivets through keelsons, bilge and side stringers, se frames, beams, are spaced about 7 diameters from butt connections of angle bars are effected by fitting


CBA ABC
CBA ABC
Frame Angle

either a bosom piece, as shown in fig. 95, or a butt covering bar, as shown in fig. 9, where a heel piece or butt covering bar covers the frame butts on top of the bar keel.

Keel Blocks and Launching Ways.

Method is a most important factor in the successful management of a shipyard, where possibly several vessels of different sizes are in various stages of construction at the same time. Without a rigorously followed system, a state of chaos would undoubtedly supervene, and great loss would ensue, simply because of the time which would inevitably be wasted. Only those who have had actual shipyard experience know how true this is.

Though a shipyard be well equipped with first-class plant and machinery, and thoroughly capable workmen and officials, there is a large amount of very important and responsible work to be completed before a single frame of the ship can be hoisted into position on the blocks.

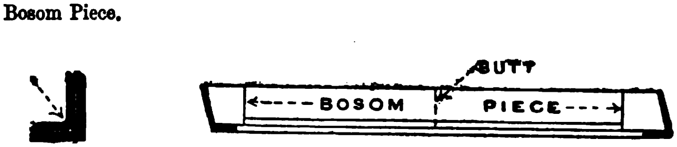


FIG. 95.—Angle Bar.

First of all, a suitable berth has to be chosen in which to build the proposed vessel. If the ground has a gentle natural declivity, all the better, as is soon discovered when the work of laying the keel blocks is about to be done. The ground must be firm, so that no sinkage or shifting of the earth takes place when the enormous weight of a large vessel is upon it. To ensure a good foundation, in some cases piles of timber are driven into the earth, and in other cases enormous blocks of timber, 12 in. or more square, are embedded in the earth, so that the uppermost surface is level with the ground. The baulks are laid in a fore and aft direction paralled to the keel line. Having secured a sure foundation, the blocks are arranged upon which the keel is to be laid. (See fig. 96.)

Everyone acquainted in any degree with ships understands that when a vessel is so far completed as to be ready for launching, what are called 'launching ways' are laid under each side of the bottom between the bilge and keel. (See fig. 96.)

And naturally, as a vessel is generally launched by the impetus created by her own weight, the launching ways must be laid on such a declivity as will cause the vessel to move by her own weight when she is freed. The declivity given to launching ways is usually about $\frac{5}{8}$ in. to 1 ft., while the declivity of the keel blocks is made slightly less, say, ½ in. to 1 ft. Consequently, where the ground has only a very slight natural slope, the stem of the vessel gets nearer and nearer to the earth every foot it travels in its journey down the launching ways. It is therefore of vital importance that a sufficient height be given to the foremost keel block, to ensure that the stem will clear the ground just before she makes her final plunge into the water. Considerable damage is sometimes done by the stem striking the dock or riverside in the operation of launching, simply because sufficient care was not taken to allow for ample clearance. Suppose the distance from the water edge to the foremost block to be 300 ft. and it is intended to make the declivity of the launching ways ⅝ths of an inch, with a clearance of, say, 1 ft. at the water edge (keel blocks ½ in. per ft.), the height of the foremost keel block will be $(300 \times \frac{5}{8}'') + 12'' = 16$ ft. 7½ in. above a horizontal base line passing through the surface of the ground at the water's edge.

But supposing the ground to have a natural declivity of ⅜ths of an inch to 1 ft., then 16 ft. 7½ in. less $300 \times \frac{3}{8}'' = 7$ ft. 3 in., the height of the foremost block above the ground line. (See fig. 97.)

Thus the declivity given to the keel blocks, and the height of the foremost block, must be determined in conjunction with the declivity of the launching ways.* See further remarks upon 'Launching,' p. 265.

Laying Off.—After the plans of a vessel have been prepared in the drawing office, the first man who takes her in hand is the loftsman. His domain is the mould loft, where, after being provided with the 'lines' plan from the drawing office, or else carefully measured or calculated particulars

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* With a ground declivity of ⅜ in. per ft., to lay the keel at a greater inclination than ½ in. per ft. is quite unnecessary, for if such were done it would make a very high, and consequently a very expensive line of keel blocks and staging.

If the keel blocks were laid at ½ in. per ft., the height of the keel blocks would give ample head room for riveting all fore and aft.

The proper method of determining the slope of keel depends on two things:—

1st. Launching the ship at such an angle with the water that the buoyancy moment should exceed the tipping moment, viz., $B \times d$ should always slightly exceed $G \times D$. (See fig. 177.)

2nd. As the ground slope is usually less than the keel slope, the keel should always be sufficiently high at the after end to permit of good riveting.

⅜ in. is a very common yard slope.
½ in. ,, ,, keel ,,
⅝ in. ,, ,, launching ,,

These are in no way imperative, but are the average of ordinary practice for ships of about 300 ft. in length.

Short boats (about 100 to 150 ft. in length) are often launched with way slopes of 1 in. to 1¼ in. to prevent them tipping off the ways.

Fine-lined ships, large yachts, and small war ships, often have ¾ to 1 in. way slope to prevent tipping, and, in addition, the ways are run further into the river than usual.

Very often the launching ways are above the bottom of the keel at the fore end. This is done so as to keep the fore cradle as shallow as possible.

In this case the foreshore or ground between the ways is dug out. This is a particularly common practice in north-east coast shipyards.

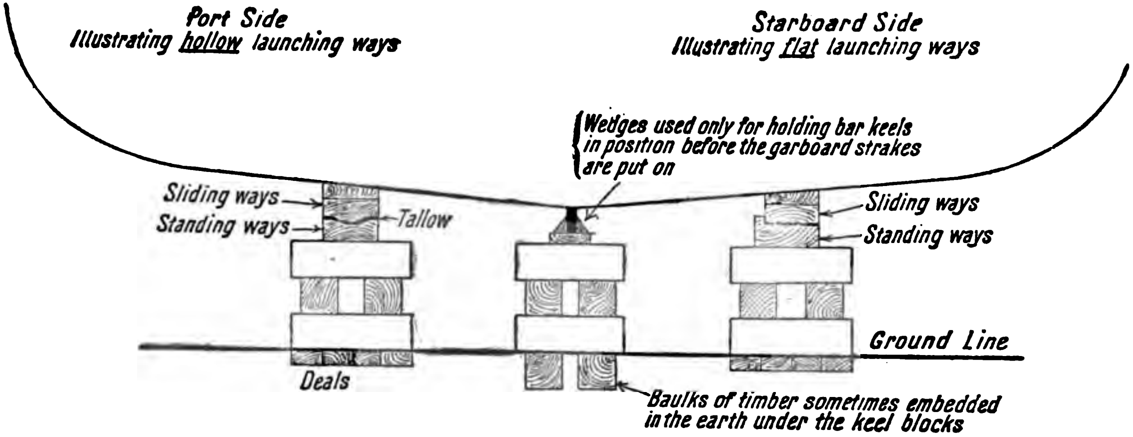
Port Side
Illustrating hollow launching ways
Starboard Side
Illustrating flat launching ways
Wedges used only for holding bar keels in position before the garboard strakes are put on
Sliding ways
Standing ways
Tallow
Sliding ways
Standing ways
Ground Line
Deals
Baulks of timber sometimes embedded in the earth under the keel blocks

FIG. 96.—Keel Blocks and Launching Ways.

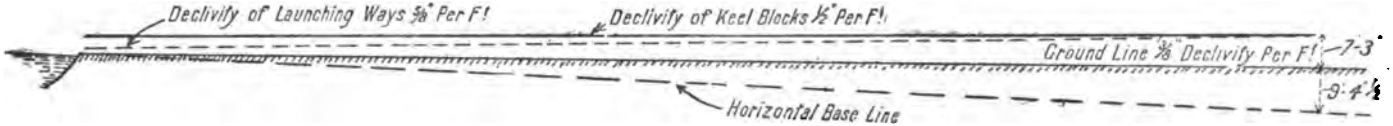
Declivity of Launching Ways ⅝" Per Ft
Declivity of Keel Blocks ½" Per Ft
Ground Line ⅜" Declivity Per Ft
7-3
9-4½
Horizontal Base Line

FIG. 97.—Declivity of Keel Blocks.

Notes.—1 ft. clearance for stem at water's edge.
4 ft. 1½ in. head room under keel at stern.

taken by the draughtsman from the 'lines' plan, he proceeds to reproduce the 'lines' plan upon the loft floor to actual size.*

In addition to these plans, the loftsman is furnished with numerous detail plans, such as the midship section, giving the scantlings of the material, and drawings of the stern frame and stem bar.

It is obvious, even assuming that the ship draughtsman has most carefully designed his 'lines' plan in the drawing office, and endeavoured to secure perfect agreement between his 'buttocks,' 'sections,' and 'waterplanes,' that when the loftsman 'lays off' the ship to full size upon the loft floor (in chalk lines upon a blackened floor), numerous discrepancies and unfairnesses may be discovered. The loftsman's work is to rectify any such irregularities, and to produce perfect harmony and fairness in all lines which make up the form of the hull.

When this is done, he proceeds to prepare the results of his labour for the workmen who are to manipulate the material for the various parts of the structure. His chief work is to prepare what is called a *scrieve board.* This consists of a rectangular area large enough to take a full-sized midship section of the vessel, made up of stout planks 9 in. or 11 in. wide, which are tightly clamped together. He then transfers from the mould loft floor to the scrieve board the midship section of the vessel (to outside of frame), and afterwards every frame between the stem bar and stern post. By means of carefully-prepared supple pine battens, which he bends round each frame on the scrieve board fixed by means of long steel pins driven into the board alternately on each side of the batten, he cuts or scrieves every frame into the scrieve board with a sharp-edged tool called a scrieving knife.

He also scrieves in all decks, stringers, keelsons, and floors. The shell plating seams or edge laps are also shown on the scrieve board, but these are usually painted on in white.

When the scrieve board is completed, the planks composing it are unclamped, and carried to the shed or shop in the shipyard near to where the frames and reversed frames are bent and the floor plates prepared. Here the scrieve board is again put together, and secured as before.

But the loftsman does much more than this. From detail plans supplied to him by the drawing office, he draws the stem bar, stern frame, rudder frame, etc., to full size, and from these, full-sized wooden templates are made, and sent to the makers of these parts whether they be forgings or castings.

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* The 'lines' plan, which is usually drawn to a scale of ¼ in. to 1 ft., consists of three principal plans.

1. A profile showing the sheer, the form of the stem and stern, the decks and stringers, and the form of longitudinal vertical sections of the vessel at certain intervals from the fore and aft middle line. These sections are called 'buttocks' in the after body, and bow lines in the fore body.

2. A body plan showing the transverse sectional form of the vessel at the outside of the frames, taken at intervals in her length from stem to stern. Upon this plan are marked all decks, stringers, keelsons, the floors, and the edges of the strakes of shell plating.

3. A plan showing the form of the rail lines, and horizontal sections of the vessel (termed waterplanes) from the keel upwards.

In a similar manner, the loftsman is responsible for the making of templates for other special parts of the vessel, and lays off or expands certain parts which need carefully dealing with in detail, such, for instance, as the stern plating round the counter, etc. A very important mould made by the loftsman is the beam mould. The standard 'camber' or 'round up' for midship beams upon weather decks is $\frac{1}{4}$ in. for every foot in the length of the beam. Thus, for a beam 40 ft. long at amidships the camber at the centre would be $40 \times \frac{1}{4}$ in. $= 10$ in.

Let fig. 98 represent the curve of the midship beam. As we travel towards the stem and stern, the length of the beam gradually becomes less and less, until at, say, x feet from the stern it is only 30 ft. The camber is *not* $30 \times \frac{1}{4}$ in. $= 7\frac{1}{2}$ in., for, as is easily seen, this would be an entirely different curve from that at amidships. The curve of every beam on any particular deck is obtained from the beam mould by setting off half its length on each side of the middle of the mould. By this means a uniform curve is preserved from stem to stern.

Decks below the weather deck may either be perfectly horizontal or have the usual camber. Generally speaking, camber is given to all decks, though not necessarily of the regulation 'round.'

FIG. 98.—Beam Camber Mould.

With the keel blocks laid, and the scrieve board prepared, the workmen are in a position to proceed with the manipulation of the steel and iron, and the erection of the vessel bit by bit upon the blocks. By the time this stage has been reached, quantities of steel plates and bars will have been received by the storekeeper, and stacked in the yard ready to be handed out as required.

As the only practicable method is to build from the keel upwards, our attention will naturally be first called to the keel.

As a comparison of the structural features of the section and profile, figs. 12 and 46, with the section and profile, figs. 48 and 49, the former about 242 ft. vessel, and the latter 443 ft., it will be seen that large vessels, though possessing a greater amount of material in their structure, are remarkably similar—practically identical, indeed, with small vessels in the detail work of construction.

While the description and illustration of the details of the construction of the vessel illustrated in figs. 10, 11, 12, and 46 will, to a considerable extent, serve our purpose, we shall not confine ourselves to this particular vessel, but when found advisable, turn to vessels of different size or type or design. This, we believe, will be the simplest and most comprehensive course to pursue.

KEELS.

The Bar Keel.—The rule dimensions of a bar keel for this vessel (fig. 10) are 9 in. × $2\frac{3}{8}$ in., the 9 in. representing the depth and the $2\frac{3}{8}$ in. the thickness. It is made of forged iron, and is ordered in separate lengths, varying from 20 to 50 ft. or more. These lengths are united so as to form a continuous bar extending from the stem bar to the stern post, to both of which it is connected. The connections of the various lengths are made by means of scarphs. The scarph connection of a bar keel to a stern frame is illustrated in fig. 99. The scarphs connecting the several lengths of keel bars to one another, and the stem bar and stern frame to the keel, are in all respects identical.

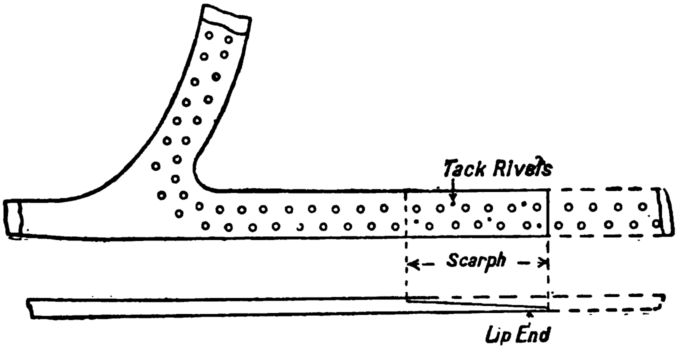


FIG. 99.—Stern Frame Connection to Solid Bar Keel.

The length of the scarph (by Lloyd's Rules) is nine times the thickness of the keel, viz., $21\frac{3}{8}$ in. The thin half length of each scarph is called the lip end. The extremities of the lip ends which check into the adjoining lengths are about $\frac{3}{8}$ths in. or $\frac{1}{2}$ in. thick. The faces of the scarphs are planed and fitted as closely as possible, otherwise it would be difficult to caulk the bottom edge of the scarph to produce watertightness, which is absolutely essential.

Bar Keel Rivets.—The diameter of rivets used in the keel is $\frac{1}{4}$ in. more than the rivets required for plates of the thickness of the garboard strakes. The rivet holes are drilled $\frac{1}{16}$th of an inch larger than the diameter of the rivet. This is to allow for the expansion which takes place when rivets are heated, which provision is specially necessary when the diameter is considerable. According to Lloyd's Rules, the garboard strake for this vessel should be $\frac{11}{20}$ths in., and the table on page 175 shows that the diameter of the rivets required for this thickness is $\frac{7}{8}$ths in. The rivet therefore for the keel is

$\frac{7}{8}$ in. + $\frac{1}{4}$ in. = $1\frac{1}{8}$ in. diameter, and the rivet hole is $1\frac{1}{8}$ in. + $\frac{1}{16}$ in. = $1\frac{3}{16}$ in. diameter.

The keel is always double riveted, that is, there are two rows of rivets. It is usual for these rivets to be arranged zigzag, as shown in fig. 99, though, on rare occasions, chain riveting has been adopted.

The rivets in each row are spaced 5 diameters apart from centre to centre. There should be about twice the diameter of a rivet between the edges of the rows of riveting. A most important rule in arranging the spacing of all rivets is, that no rivet should come nearer to the edge of a plate or bar than a distance at least equal to the diameter of the rivet. Now the garboard strake is never brought to the bottom of the keel, but is kept up about $\frac{1}{4}$ or $\frac{3}{8}$ths of an inch. This is in order to permit of more satisfactorily caulking the bottom edge, and also to preserve the caulking in the event of the keel chafing over sandy bottoms or river bars. In some cases, it is found to be necessary to fit chafing plates or shoes over the bottom of the keel to preserve the lower edge of the garboard strake from wear from this cause. It also reduces the possibility of severe straining of the rivets which might arise in the event of the vessel grounding upon the keel with a list, and one of the garboard strakes taking the weight of the vessel. The bottom rows of rivets must be kept *at least* one diameter of the rivet hole from the bottom edge of the garboard strake. At the same time, to keep the rivet too far from the edge of any plate which has to be caulked is a distinct objection, as it is difficult to satisfactorily close up the seam.

When the space between the rows is made more than two diameters of the rivet, it sometimes throws the top row of rivets so high that sound riveting is almost impossible. If the top rivets are upon the bend of the garboard strake, the work cannot be closed up, and on looking down between the floors, the rivet necks can be distinctly seen. Such work, needless to say, is most objectionable.

All rivet holes in the keel bars are drilled before the bars are fixed in place upon the blocks, excepting those in the lip ends of the scarph, which should be drilled after the keel has been fixed in position on the blocks, so as to avoid any blindness in the holes, which would be particularly objectionable in this locality. Before the frames are erected, and the garboard strakes are put on, the keel lengths are held in position by riveting them together by means of about half a dozen $\frac{7}{8}$ths in. tack rivets through each scarph, spaced where found most convenient, and as far away from the other rivets as possible.

The scarphs are caulked before the garboard strakes go on, so as to ensure that no water finds its way into the vessel through the connections.

The bar keel is held in position on the blocks by means of chocks as shown in fig. 96, until the frames are erected and the garboard strakes can be put on.

Side Bar Keel.—In a vessel with a side bar keel, the centre through-plate (centre keelson) is continuous all fore and aft, and extends from the bottom of the keel to at least the height of the top of the floors. (See figs. 11 and 135.) The keel proper is usually made the same depth as required for a solid bar keel; and the total thickness of the centre girder and side slabs combined is equal to a solid bar keel. A most important condition which should be aimed at in the construction of side bar keels is, that the butts of the side bars and the centre through-plate, as well as the butts of the garboard strakes, be kept as far from each other as the lengths of the plates and bars will permit. For the reasons given, in dealing with bar keels the garboard strakes should be kept at least ¼ in. from the bottom of the keel. The connection of the side bar keel to the stern frame is illustrated in fig. 100; and in an identical manner, the stem bar also is connected to the side bar keel. The riveting in all respects is similar to the riveting previously described for solid bar keels.

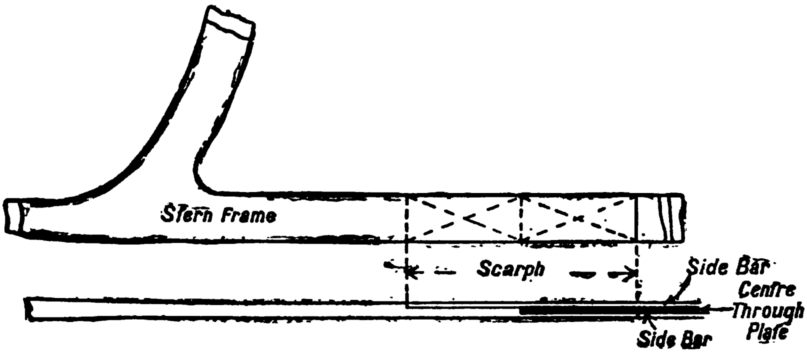


FIG. 100.—Stern Frame Connection to Side Bar Keel.

Flat Plate Keels.—A flat plate keel resembles an ordinary strake of outside shell plating, with the exception that it is of much greater thickness than the adjacent strakes. (See figs. 12, 48, and 58.) This is necessary, not only because of the wear and tear to which this plate is often subject, but because, in conjunction with the centre through-plate, which stands upon and is strongly attached to it, it assists in giving longitudinal strength. A flat plate keel is usually about 36 in. in width for ordinary vessels. The angle bars, by means of which the connection to the centre through-plate is made, are also of exceptional size and thickness. The spacing of the rivets through the plate keel and these angles is about 5 diameters apart. The keel plate has the further assistance of the garboard strakes, which, though less than the keel plate thickness, are greater than the adjacent plating.

In some cases, a horizontal bar keel, or rubbing piece, as it is sometimes called, is attached to the centre of the keel plate by large rivets passing through both the keel plate and the horizontal flanges of the angles at the bottom of the centre through-plate. (See fig. 48.)

Frames, Reverse Frames, and Floors.

Frames.—The frames which, in figs. 6 and 10, extend continuously from the top of the keel to the gunwale, or to the poop, bridge, or forecastle deck stringer plate, are ordered in straight bars, and bent to the required shape in the shipyard by the frame benders. The rivets connecting the frame bar to the reverse bar, and the frame bar to the shell, are spaced 7 to 8 diameters apart. All the rivet holes in the frame bar are punched before it is bent to its required shape, excepting those we shall now mention.

First.—The rivet holes on the turn of the bilge, which are apt to elongate up, owing to the amount of bending which takes place here.

Second.—The rivet holes in way of all the edge laps or landings or seams of the strakes of the outside shell plating, for as only one rivet is put through the frame in the way of shell landings (excepting in oil steamers; see p. 158) so as not to unduly weaken the frame, it is most essential that the hole be perfectly fair, in order to ensure the best workmanship. Although the positions of the laps are marked upon the frames before they are erected, it often happens, in checking the fairness of the fore and aft sight edge lines of these laps upon the ship herself, which is done by pinning a batten upon the frames after they are erected, a slight deviation has to be made from the marks upon the frames. Hence the necessity of omitting the punching of these holes, and drilling them at a later stage when all is fair.

Third.—The holes for beam knees are left unpunched also, with the exception of one hole, as, in fairing up the beam or sheer line, one or more beams might need slightly raising or lowering after being temporarily placed in position. The single hole punched in the knee is further necessary in order to attach the tackle for hoisting the beam up. The positions of the shell landings are obtained from the scrieve board by bending a light wooden strip round the particular frame being dealt with, and marking the laps upon it. On allowing the strip to spring straight again, it is laid upon the straight frame bar, and the position of the laps transferred. The space between the rivet hole in one lap and the rivet hole in the next lap is divided off into equal spaces representing, as nearly as possible, about 7 or 8 diameters of the rivet.

Punching.—It is of the greatest importance in punching, not only the frames, but all plates and bars throughout the vessel, that this be done from the faying surfaces.

The faying surfaces are those which have to bear against each other when riveted together, as, for instance, the faces of the frame and reverse angle flanges. The reason for this is, that in punching a plate or bar, the action of the punch is to leave a rag edge on the opposite side from that on which the punch enters the material. This would be a hindrance to any other plate or bar bearing close against it, which is absolutely essential to secure watertight and, in all respects, satisfactory work. Moreover, the conical form of the punched rivet hole is better filled by the swelled neck of the rivet (see p. 169, Riveting).

Having punched the frame bar, the next step is to get it bent to shape. Generally, under the same shed in which the scrieve board is laid, there are what are known as the frame furnaces. In front of these furnaces there are laid large rectangular slabs of cast iron, 5 or 6 ft. square, and about 5 in. thick, which are perforated all over their surfaces with round or square holes about 1½ in. diameter. These iron blocks are so arranged as to form a perfectly horizontal surface of sufficient area to take the largest frame in the vessel.

In order to get the shape of the particular frame to be bent, a mould is made by means of a long strip of iron, called a set iron, which usually measures about 1½ in. wide by ½ in. or ⅜ths in. thick. When this has been bent to the shape of the toe of the frame on the scrieve board, it is taken to the cast iron blocks, and pinned down. (See fig. 101.)

However, not only have the frame bars to be bent to the shape of the section of the vessel, but they have to be bevelled also. Fig. 102 will illustrate this.

The frame angle has a long and short flange. The size of the frame angle for the vessel in figs. 6 and 10 is $4\frac{1}{2} \times 3 \times \frac{8}{20}$. The short flange *always* goes against the shell, and the long flange points towards the interior of the vessel, perpendicular to the fore and aft middle line. It will thus be seen that over part of the midship length of ordinary cargo vessels, where the form of the section is constant, the angle produced by the flanges of the frame bar is a perfectly right angle. Towards the ends of the vessel, however, where the hull tapers in to the stem and stern, the angle produced by the flanges of the frames must necessarily change. Did the shell flanges of all the frames point in the same direction, then at one end of the vessel the angles produced would become very obtuse, and at the other, very acute. But with an acute angle, or as it is called, a closed bevel, to get good riveting is most difficult, and in some cases impossible, as the head of the rivet cannot be properly laid up. It thus becomes necessary, in order to get open frame bevels at the ends of the vessel, to reverse the frames at one end, that is, the shell flanges of the frame bars point towards amidships from both ends of the vessel. The reversing of the frame takes place at amidships. (See fig. 102.)

The bevelling of the frame bars can be done either by hand or by machinery. In small vessels, both the bevelling and the bending can be done in one heat, but for larger vessels two heats may be necessary. The amount of bevel to be given to the frames is supplied by the loftsman on a bevel board.

A possible danger in hand bevelling is that the shell flange may be made somewhat concave between the heel and the toe of the bar. This could only conduce to unsatisfactory riveting, hence it is necessary to carefully guard against it, and in some cases to chip off the projecting heel of the bar.

In machine bevelling, the bar is bevelled from the heel, and this objection exists only to a very small extent.

To bend the frame, it is drawn out of the furnace after it has reached a full heat, and one end is pinned down to the end of the set iron, while the other is worked round to its shape, and pinned down and kept in position on the blocks by means of iron dogs and pins. (See fig. 101.) An important feature in the bending of angle bars is, that in the process of cooling, more contraction takes place at the heel of the bar where the material is thickest than anywhere else. The result is, that in a bar bent *from* the heel (as is the frame bar), the contraction causes the bar to somewhat straighten itself, producing a reduction in the curvature. Knowing this, the frame benders, guided by experience, give more curvature to the frame when it is in a heated state than the scrieve board indicates, with

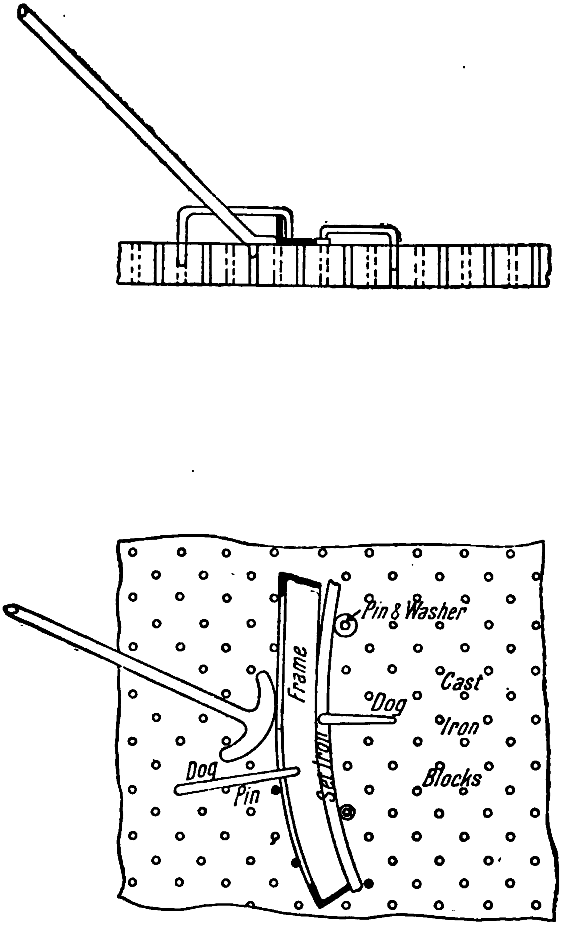


Fig. 101.—Frame Bending.

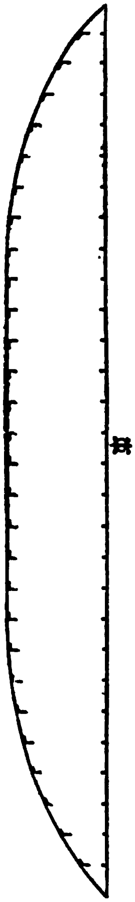


Fig. 102.—Showing bevelling of Frames.

the effect that when the frame bar is cool, it has approximately come to the desired shape,—so near indeed, that a few blows from a hammer, when it is cold, brings it to the correct curvature. It is carefully tested on the scrieve board before any riveting is done. The corresponding frame bar for the other side of the vessel is made in a similar manner, and the two sides tested by laying one upon the other.

We observed in the last chapter, that the amount of external water pressure on the outside of a vessel is greatest where the immersed girth is greatest, and it naturally follows that greater weight is likely to be carried where the hold capacity is greatest. Therefore more strength is required in the transverse framing in the full middle body of a vessel than towards the ends, where she gradually fines down into the stem and the stern. Lloyd's Rules thus stipulate that for three-fifths of the vessel's length amidships, the frames are to be $\frac{8}{20}$ths thick (fig. 10), and for the remaining one-fifth at each end, they need only be $\frac{7}{20}$ths thick. Similarly, the floors, which are $\frac{9}{20}$ths thick for three-fifths length amidships, are gradually reduced down to $\frac{7}{20}$ths at the ends.

Reverse Frames.—Like the frames, the reversed frame angles come into the shipyard in straight bars. They are considerably smaller than the frame angles, being, for the vessel in figs. 6 and 10, only $3 \times 3 \times \frac{7}{20}$. The holes for rivets connecting the reversed frames to the frames and floors, and those which take stringers and keelsons, are all punched after the bar is bent. The reversed frame is bent and bevelled in a manner very similar to that described for the frames. The set iron is made to the shape of the toe of the frame from its uppermost extremity down to the bilge where it leaves the frame and takes the form of the upper edge of the floor plate.

Unlike the frame angle, the heel of the reverse frame comes against the set iron, and in cooling—most contraction taking place there—the tendency is for the bar to bend more than is given to it on the blocks. In this, again, the experience of the frame bender guides him in making due allowance, and when the bar has cooled, and is finally tested upon the scrieve board, a few blows from a hammer is generally sufficient to make any necessary correction. The holes in the unpunched flange taking the frame are transferred from the frame by laying the frame bar upon the reverse bar, and marking the rivet holes by means of a whitened wooden cylinder which is pushed through each rivet hole. The remainder of the holes connecting the reverse frame to the floors are spaced 7 to 8 diameters apart, and punched. Holes for keelsons and stringers are always omitted, and punched or drilled at a later stage. (For heights to which reversed frames extend in one, two, three deck, spar deck, and awning deck vessels, see Chapter VI., pages 110 to 123, 'Types of Vessels.')

In the engine and boiler space of steam vessels, double reversed frames should be fitted to every floor, and extend at least from bilge to bilge. In figs. 6 and 10 the reversed frames extend alternately to gunwale and to the top of the hold beam stringer angle; and in the way of the engine and boiler space, the double bars extend from upper bilge stringer to upper bilge stringer.

The spacing of the rivet holes in the flange connected to the frame angle will naturally be the same as the spacing in the frame (7 to 8 diameters of rivet) from which they were transferred. The rivets in the same flange taking the floors are spaced 7 to 8 diameters also. The rivet holes in the other flange taking the ceiling and sparring must be spaced to suit the width and arrangement of the battens.

Floors.—In the case of very small vessels, the floors are usually in one piece from bilge to bilge. But in larger vessels this is impracticable, and the plates forming the two parts of the floor are lapped on one and the other side of the centre line alternately. The lap must be treble riveted (see fig. 6) or, if the butt be strapped, double straps treble riveted should be used.

As we have previously observed, the floors extend up the bilge in a fair curve to a height above the top of the keel of twice the depth of the floors at the middle line. But as it adds very materially to the cost of plates to have them cut hollow to shape by the manufacturer, the custom in all shipyards is to order all floor plates so that the top edge is a perfectly straight line. Indeed, only rarely are any plates ordered with a hollow in them, for the reason given. What the draughtsman does in ordering floor plates is to expand the floor with the top edge perfectly straight, and in order to minimise waste, he orders the floor plate somewhat like the plate shown in fig. 103. The first operation, then, in dealing with the floor plate, after it has arrived on the shipbuilder's premises, is to curve its top edge to the shape of the particular floor on the scrieve board. Here, again, a set iron is bent to the required shape, and pinned on the iron bending slabs. The floor is put into the frame furnace and heated to a white heat. It is then brought out of the furnace, bent round the set iron, and pinned down with dogs. It is hammered when necessary, and care taken to prevent buckling. As the floor plate is inserted between the frame and reversed frame at the bilge — that is, just where the frames and the reversed frames diverge—the floor plate is heated again at the ends, and hammered out so as to produce a gradual wedge-shaped taper. (See fig. 104.)

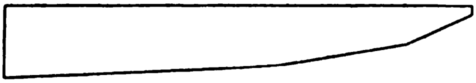


Fig. 103.—Floor Plate as ordered.

After the floor has cooled, the next step is to curve its outer edge to suit the frame. It is taken to the scrieve board, its upper edge is adjusted to its own floor curve, and the centre line over the keel is marked upon it. Its own frame, which is already bent, is then laid upon it, and the curve of its outer edge marked with chalk. At the same time, the rivet holes are transferred from the frame by the whitened wooden cylinder. In a similar way, by laying the reverse frame upon the floor, the rivet holes are transferred. The floor plate is then carried away and sheared—not, however, to the exact frame edge line, but about ¼ in. from the frame edge, so that when the floor attached to its frame is in position in the ship, there is no doubt about the frame flange bearing hard upon the shell (see fig. 104). According to the 1st numeral of this vessel (figs. 6 and 10) the depth of the floors on the keel should be 22½ in., and at three-fourths of the half-breadth from the middle line the minimum rule depth $\frac{22\frac{1}{2}}{2} = 11\frac{1}{4}$, and the height from the base line—top of keel—to the top of the floor at the extremities should be $22\frac{1}{2} \times 2 = 45$ in.

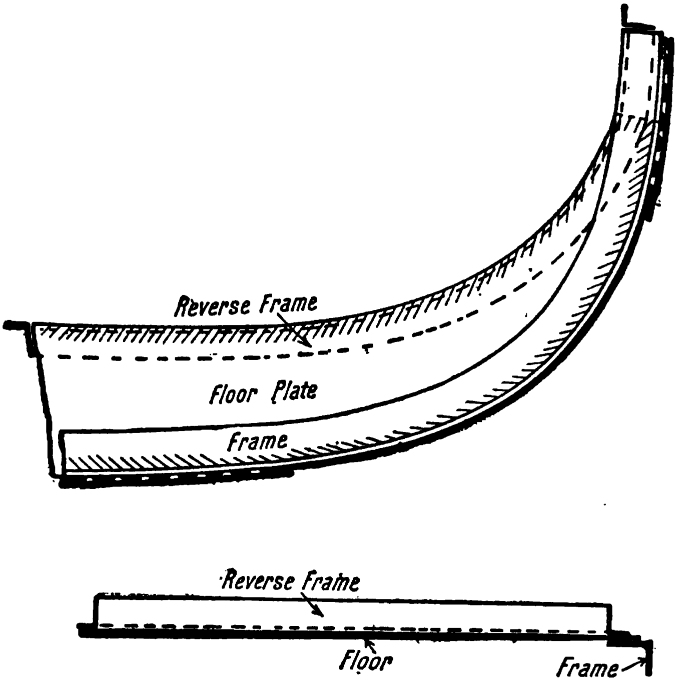


Fig. 104.—Showing Floor at Bilge.

Both the frame bars and the reversed frame bars for the two sides of the vessel butt at the middle line—the frames on the top of the keel, and the reversed frames immediately under the centre keelson. On account of the unavoidable interruption in the continuity of these parts of the transverse framing, butt straps must be fitted. Thus, covering the frame butt, we have a piece of angle bar 3 ft. long, of the frame size, riveted on the opposite side of the floors (figs. 6 and 9). This butt strap, or *heel piece*, as it is called, not only affords strength at the butt, but offers an additional means of securing a good connection to the garboard strakes, which in turn carry the bar keel. This is an important point, as the only connection which the bar keel has to the vessel itself, is by means of the garboard strakes to which it appears to hang. Hence the bar keel is sometimes termed a 'hanging' keel. The reversed frame butt strap, or lug piece, is also fitted to the opposite side of the floor plate (figs. 6 and 9). Not only does it perform the function of a butt strap, but it also provides a double means of connection between the largest and the chief keelson in the vessel to the transverse framing (see figs. 9 and 10). Indeed, wherever keelsons or stringers cross over the transverse frames, the connection should be made by means of these double reversed bars or lug pieces, even though no butt occurs in the ordinary reversed frame, and the lug should be long enough to take three rivets. (See fig. 105.)

Like the frames, and for the same reason, the floor plates are thicker over the three-fifths length amidships (from $\frac{1}{20}$th to $\frac{2}{20}$ths) than at the ends.

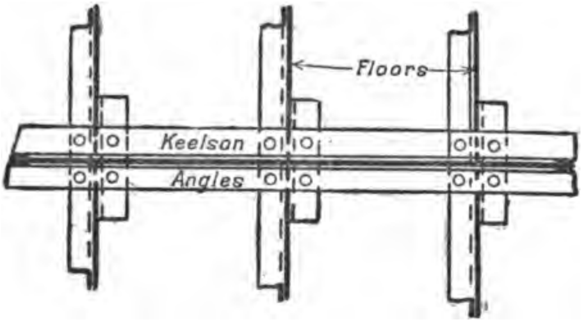


Fig. 105.—Showing Lugs upon Floors for Keelson Connection.

The special requirements of transverse framing in way of the engine and boiler spaces will be dealt with at a later stage under that heading.

Erection of Transverse Framing.—When the frames, reverses, floor-plates, and beams have been prepared, and their accuracy tested upon the scrieve board, they are carried to a staging at the stem of the vessel, and riveted together with or without the beams. They are then hoisted into their respective positions indicated upon the keel, and first of all (remembering the declivity of the blocks) given such a rake (angle of inclination) as will bring them perpendicular to the keel. This operation is termed 'plumbing.' The process of adjusting the frames, so that they cross the keel at perfect right angles, is called 'horning.' In a vessel with a double bottom, this expeditious system of erecting complete transverse frames cannot be carried out, the double bottom having to be erected first in the order of keel, centre through-plate, floors, tank margin plate, and the frame legs hoisted into position after the framing of the double bottom has been practically completed.

Double-bottom Framing.—The details of the transverse framing in vessels having double bottoms with continuous centre through-plates standing upon flat plate keels have already been fully described in Chapters IV. and VI. (see Water-ballast Arrangement). It might be noticed in passing, however, that where the floors are solid from centre through-plate to tank margin plate, the angle bar upon the lower edge of the floor plate by means of which the connection is made to the shell, need not have flanges larger than the smaller of the ordinary frame flanges. But where floors come upon alternate frames, as shown in fig. 85, with brackets only upon alternate frames, the frame angle in the tank should be of the full size. Both frame and reverse frame angles upon solid floor plates are sometimes dispensed with, the connection to shell and inner bottom being made by flanging the floor plates. (See fig. 64.)

Where side bar keels with continuous centre through-plates from bottom of keel to tank top are adopted, as shown in figs. 11 and 135, it is common for the frame angle in the tank to be continuous from margin plate to margin plate. In such case, a triangular hole must be notched out of the centre through-plate immediately above the keel, to allow the frame bar to pass through. In the erection of this form of double bottom upon the blocks, the centre through-plate and side bars are first fixed in position, followed by the tank frame bar which is held up by means of shores, and after this, the floors with reverse bars and angles for the connection to the centre through-plate and tank margin plate are hoisted up and riveted to the frame.

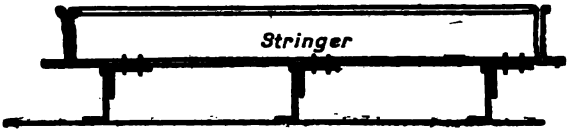


FIG. 106.—Bulb Angle Frames with large Lug for Stringer Connection.

Z Frames.—While the Z frame section of frames is preferable to the ordinary frame and reverse, its costliness, and the increased difficulty in bending and bevelling, has made its adoption comparatively rare in merchant shipbuilding, but in the Royal Navy it is extensively used. Fig. 64 is framed with Z bars.

Bulb Angle Frames (in lieu of frame and reverse).—When bulb angle frames are adopted (and also Z frames), it is usually in vessels with double bottoms; the shorter lengths of frames terminating, as they do, at the tank, renders the operation of bending and bevelling more easy of accomplishment. One noteworthy point about the bulb angle frames is that they have no fore and aft flange to which the stringers and sparring in the holds can be attached. This difficulty, however, is got over in the case of the stringers by fitting to that side of the transverse flange away from the bulb, a lug with a flange large enough to take double rivets. (See fig. 106.) The sparring is fixed by means of cleats.

Channel Bar Frames.—This excellent section, combining both frame and reverse bar, is now extensively adopted, especially in large vessels with a long uniform midship body for which the channel frames require no bevelling.

The difficulty of both bending and bevelling channel bars for frames, and the still greater difficulty of performing satisfactory riveting where much bevelling takes place, is sufficient reason for dispensing with them at the ends of vessels. Though channel frames may be used in vessels with ordinary floors, yet, like Z frames, they are usually adopted for the frame legs only in vessels with double bottoms. In some cases, extra deep channel frames have been used as compensation for an omitted tier of hold beams.

Deep Framing.—While the two large angles which go to make up what are termed deep frames take the place of the ordinary frame and reversed frame, their chief function, as has been pointed out in Chapter IV., is to compensate for a tier of hold beams which are dispensed with. Instead of fitting together the two angles in the same fashion as is usual for the ordinary frame and reverse—the toe of the frame being flush with the heel of the reverse frame—the connection is made by means of a 3 in. lap only, in which case it is preferable to fit the angles together as shown in the detail section in fig. 12. The lug piece which is usually fitted in order to get a good connection between the stringers and the transverse frames, is placed on the back of the reversed frame (see fig. 12). This is better than fitting the frame and reverse as shown in fig. 107, where not only is a piece of packing iron required, but satisfactory riveting is with difficulty obtained. Figs. 12 and 48 are framed on the deep frame system.

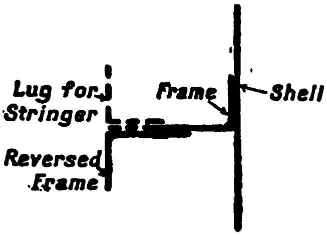


Fig. 107.—Inadvisable method of fitting the Reversed Frame in Deep Framing.

Like channel frames, deep framing is usually adopted for the frame legs in vessels with double bottoms. The bending and bevelling is done as described for ordinary frames.

Web Frames. See also Chapter IV.

The width and spacing of web frames in lieu of a tier of hold beams is governed by the depth of the vessel, while the thickness of the plates is usually similar to that of the ordinary frames. In conjunction with web frames, web stringers of the same width as the web frames are fitted intercostally between the web frames. The number of these also depends upon the depth of the vessel.

A web frame is made up of one or more plates connected by treble riveted laps or straps. The connection to the shell is made by an angle of the frame size, and on the inner edge, by two angles of about the reversed frame size or one equivalent angle.

A section through the web stringers is shown upon fig. 11. It will be noticed that they are connected to the shell by an intercostal angle between the frames, and to the reverse frames by an angle which is intercostal between the web frames. On the inner edge of the web stringer plate are two small angles which may be substituted by a single angle as for web frames. The connection of the web stringer to the web frames is made by double angles, and also by diamond plates. (See midship section, fig. 48.) The connection of the web frames to the tank side is made by double angles also.

In order to make the transverse strength afforded by web frames as continuous as possible right round the transverse circumference of the hull, extra strong through beams with deep knees are fitted to the head of the web frames where practicable.

Figs. 11, 67, and 71 are midship sections of vessels built upon the web frame system. The sectional profile in fig. 70 will afford a good idea of the general arrangement of web frames and stringers.

Beams.

As a general rule, it may be stated that under iron or steel decks it is preferable to fit beams to *every* frame; that is, when the frame spacing is somewhat similar to what would be required according to Lloyd's Rules. They may consist, in small vessels, of plain angles, and in larger vessels of bulb angles or channel bars. The reason for this is, that if, with an average frame spacing of, say, 24 in. in a vessel 250 ft. in length, the beams were placed upon the alternate frames (4 ft. apart), the comparatively thin iron or steel deck, which structurally would be sufficient for such a deck, would possess the tendency to fall hollow between the beams, which is most objectionable and unsightly. To place beams upon alternate frames under steel decks should only be attempted in very large vessels with thick deck plating. Indeed, Lloyd's Rules distinctly state that while it is preferable that beams be fitted to every frame under steel decks, it is only when the steel deck exceeds $\frac{7}{20}$ths of an inch in thickness, that beams on alternate frames are permitted in their classification.

The steel upper deck of the vessel shown in fig. 12 is $\frac{6}{20}$ths in. in thickness, and the beams under it are placed upon every frame (24 in. apart). In figs. 48 and 49 the uppermost or shelter deck is only $\frac{6}{20}$ths in. in thickness, and the beams under it are again upon every frame, but the upper and main decks, which are of steel $\frac{7}{20}$ths in. in thickness, have their respective beams on every alternate frame. Where a system of widely spaced frames is adopted, as has been pointed out in figs. 72 and 73, in which the spacing is 36 in., the beams under steel decks must of necessity come upon every frame.

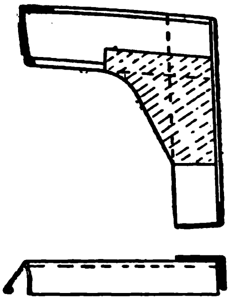
As the tendency to fall hollow between the beams in vessels with wood decks only practically does not exist, it is usual to fit beams of stronger section on alternate frames. They may consist of large bulb angles, tee bars, bulb tee bars or butterly bulbs, bulb plates with double angles on top, or channel bars, varying in dimensions according to the greatest breadth of the vessel.

Like the frame and reversed frame angles, the beams come into the shipyard in straight bars. But, as we have seen, all beams on weather decks, at any rate, should have a 'camber' or 'round up' of $\frac{1}{4}$ in. to every foot of midship beam. This result is obtained by cold bending in a 'Squeezing Machine.'

The length of every beam in the ship's deck is obtained from the mould upon which they are indicated. Having cambered the beams, and cut them to their respective lengths, the next step is to prepare the knees.

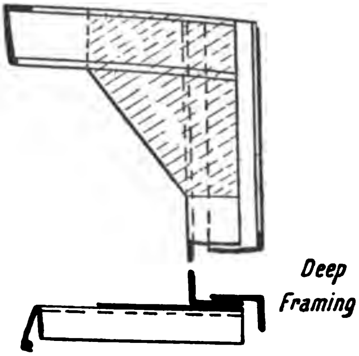
Lloyd's require that the depth of beam knees be at least two and a half times the depth of the beam. The knees may be either welded or bracketed.

The welded knees are generally made by cutting off part of the bulb, and welding to its extremities a piece of plate of the thickness of the beams (see fig. 108), where the welded plate is shown by hatched lines. When the welding is well done, a stronger knee is formed by carrying the bulb round the edge of the knee.



Plan showing the Beam fitted into the Bosom of the Frame.

FIG. 108.—Bulb Angle Beam with Welded Knee.



Plan.

FIG. 109.—Bulb Angle Beam with Bracket Knee.

Bracket knees, as shown by hatched lines in fig. 109, consist simply of bracket plates riveted to the back of the vertical flange of the beam. In both these cases, the knees fit into the bosom of the frames (see plan in sketches). Beam knees of this size (14 in. in depth) should have, *at least*, four $\frac{3}{4}$-in. rivets connecting them to the frames, but not more than two rivet holes should be punched in any beam knee, or in the frame before the beam has been hoisted into place and adjusted.

Knees for plain angle beams, such as would be used for upper decks in smaller vessels, and for the poop and bridge of the vessel illustrated in figs. 12 and 46, are made in exactly the same manner as described for bulb angles.

Having prepared the knees, the spacing of the rivet holes in the horizontal flange of the beam taking the deck is the next operation. This is a more important work than one would at first imagine, and requires very considerable care. The general rule is, that rivets connecting an iron or steel deck are spaced from 7 to 8 diameters apart, but, as we shall show, the regularity of any such spacing may be greatly interfered with. Reference to the deck plan of the vessel in fig. 143 will help to make this clear. On the deck stringer plate, and round all deck houses, hatches, casings, etc., there are angle bars forming the connecting means between the deck and the sheer strake, or deck houses, or hatch coamings, etc., as the case may be. The positions of all such bars as these are supplied to the outside workmen by the ship's draughtsman, either on a deck plan, or on what is called a beam list. Then, again, care has to be taken to set off all the rivet holes in the edge laps of the strakes of deck plating. After precautions have been taken to carefully mark off the positions of these particular rivet holes, the remaining rivet holes are spaced, as nearly as possible, 7 or 8 diameters apart. The holes are then punched.

The midship section, fig. 48, shows a section of the deck through a hatchway, and will further illustrate the points just mentioned. See also fig. 115 (channel beam).

When a wood deck is laid upon the beams, then, in addition to marking off the positions of deck angle bars, tie plates, etc., the holes in the deck flange or flanges of the beam through which the wood deck bolts pass, must be arranged to suit the width of the deck planking. Wherever beams are fitted to every frame or alternate frames, they must be tied together so as to preserve the proper spacing between them, and thus keep them in their correct positions relatively to one another. When a steel or iron deck is laid upon the beams, the deck itself admirably performs this function, but when only a wood deck is laid upon the beams, continuous iron or steel tie plates, laid in a fore and aft direction across the beams, assisted when necessary by diagonal tie plates, are required. These tie plates vary in width from 6 in. to 30 in. or more, and in addition to serving the useful purpose just mentioned, act like a steel deck in distributing stresses thrust upon the deck in any locality (from masts, etc.) from beam to beam, and to the stringer plates.

Plates somewhat similar to these tie plates should be fitted to the beams along the sides and round the ends of the hatchways, engine and boiler openings, companion ways, and all other deck openings, so as to get a better connection for the angle bars which go round the coamings of all these openings.

In the way of all hatchways, the beams necessarily only extend from the frame to the hatch coaming. When the hatchways are very long, and when they come in the middle length of the vessel, the result must be a very serious reduction in transverse strength, unless adequate measures are adopted to compensate for the interruption in the continuity of these transverse girders. In any case, it is necessary to carefully protect all deck openings, especially when situated upon the weather deck,—these being most exposed to the attacks of shipped seas, etc. This protection is afforded to hatchways by fitting vertical side plates, or *hatch coamings*, along the sides and ends of the openings, and carrying them to a height of at least 2 ft. 6 in. from the deck. These hatch coamings not only afford protection to the hatch openings, but a means of binding together the beam ends, and provide the compensation previously referred to.

First of all, we notice in the profile, fig. 46, that at all hatch ends an extra strong deep beam is fitted, consisting of a bulb plate and an angle (or it may be a strong channel bar or some equivalent), instead of the ordinary bulb angle beam. At the hatch ends, the coaming plate is carried down over this beam to the top of the bulb, and securely riveted to it with a double row of rivets as shown in the section of the beam, fig. 110.

Instead of the side or fore and aft hatch coaming plates extending from the deck only to their prescribed height, they are carried down well over the ends of all the half beams, or flanged round the bottom of the beams, as shown in figs. 48 and 115. When the hatch corners are round, which is the more preferable method of construction in every respect (except for cheapness), the coamings are continuous all round the hatchway, the separate plates composing the whole coaming being connected by double riveted butt straps. These hatch coamings should be made of good stout plates, $\frac{8}{20}$ths in. or $\frac{10}{20}$ths in. thick, in vessels of average size. It will now be seen what an excellently strong and suitable arrangement the hatch coamings become, upon which to hang, as it were, the ends of the beams which are necessarily cut in way of all hatches. By the hatch end coaming plates being well riveted to the strong hatch end beams, the side coaming plates become exceedingly strong fore and aft girders well able to carry the beams and the deck at the hatch side, that is, of course, in conjunction with the assistance afforded by the hold stanchions, which are fitted along each side of all large hatchways (unless special compensation is introduced

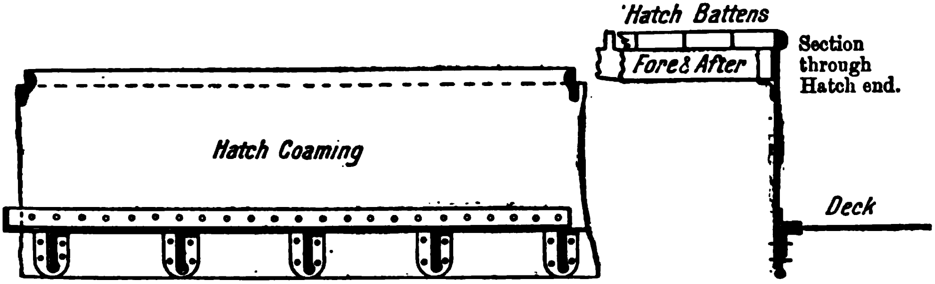


FIG. 110.—Side Elevation of Hatch Coaming plate, showing angle connection to deck plating and collars on beam ends.

for dispensing with them), and well connected to the beams. Indeed, the hatch coamings are formed into a strong, rigid girder framework, well connected to the main structure of the ship at the hatch ends. It is when labouring at sea that the section of the vessel in way of the hatches is liable to develop weakness, but as shown in the further reference to hatchways (p. 250), transverse stiffness is afforded by the introduction of portable transverse web plates between the coamings. (See figs. 46 and 115.)

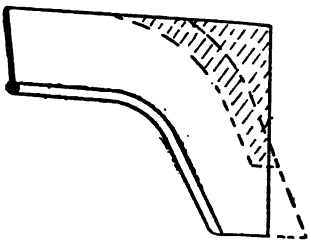


Fig. 111.—Bulb Plate Turned Knee.

When the hatch coamings have square corners, the side and end plates are connected by means of a corner angle bar.

The half beams in way of the hatchways are connected to the hatch coamings by means of angle collars, as shown in fig. 110.

When the strong beams at the ends of hatches are made up of a bulb plate and angle, as shown in figs. 46 and 110, the beam knee is made in one of the following ways: either the beam is heated and the end turned down, and a piece of plate welded on the corner as shown in fig. 111, or else the bulb is chipped off the end of the bulb plate and a piece of plate or bulb plate welded on, as shown in fig. 112.

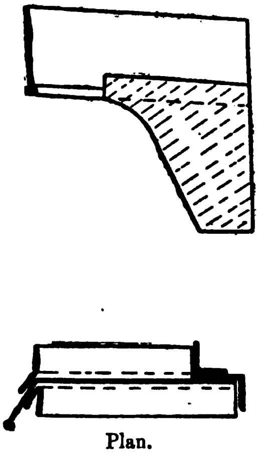

Plan.

Fig. 112.—Bulb Plate Welded Knee.

It is also common to fit bracket plate knees to bulb plate beams, as shown in fig. 113.

In order that the bracket plate may fit close against the bulb plate, the bulb on one side must be chipped off.

The beam is necessarily cambered, and, like the ordinary beams, fits into the bosom of the frame as shown in fig. 112. In welded knees, preferably the bulb should be preserved right round the knee, and should finish upon the outside of the frame, as shown in fig. 48, as it affords both stiffness and strength to resist collapse under severe, transverse, racking stresses.

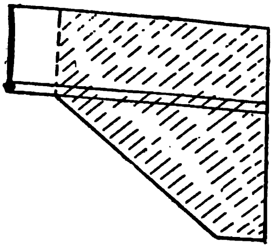
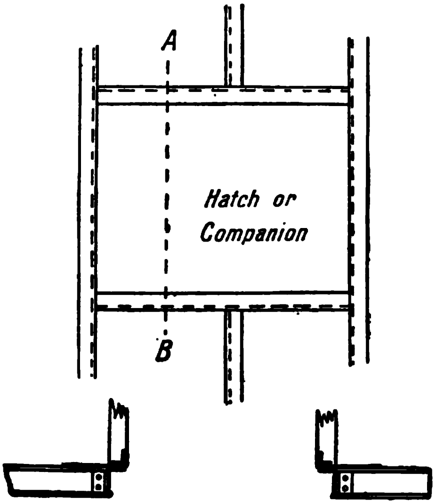


Fig. 113.—Bulb Plate Bracket Knee.

When we come to the upper deck beams in way of the engines and boilers, again the ordinary bulb angle beams are cut in way of the openings, with only an occasional specially strong beam run continuously from side to side of the vessel. These half beams are supported in a way similar to that explained for beams at hatch sides. Stout steel coaming plates are fitted down over the beam ends, to which the half beams are attached by angle collars or lugs.

In the decks of most steam vessels, it is very common to see small hatch openings, say 2 or 3 frame spaces (about 4 or 6 ft.) in length, and 2 or 3 ft. in breadth. (See fig. 143, deck plan.) These are used for trimming coal into the bunkers, or, when at the ends of the vessel, as entrances to store-rooms (boatswain's, sail, etc.). When they open into coal bunkers only, the beams usually run through them without interruption, and the coal is trimmed through the spaces between the beams. In such cases, the beams are usually protected from damage by falling coal, by riveting a piece of convex iron to the top flange of the beam. In such cases, the coamings are simply erected upon the deck, there being no necessity to extend them further down.



Section through A.B.

FIG. 114.—Beam cut for Hatchway or Companion-way.

Where the deck openings are entrances to store-rooms, the space is generally left entirely open, and the beams are therefore cut at the sides of the hatchways, as shown in fig. 114.

The half beams may be supported by being attached to fore and aft coaming plates carried down below the beams, as previously described for large hatchways, or else a strong bulb angle or channel bar may be made to form the 'fore and after' to carry the half beams, as shown in fig. 114.

A reduction is sometimes made in the thickness of the beams towards the vessel's ends. This reduction is usually made upon all beams which are less

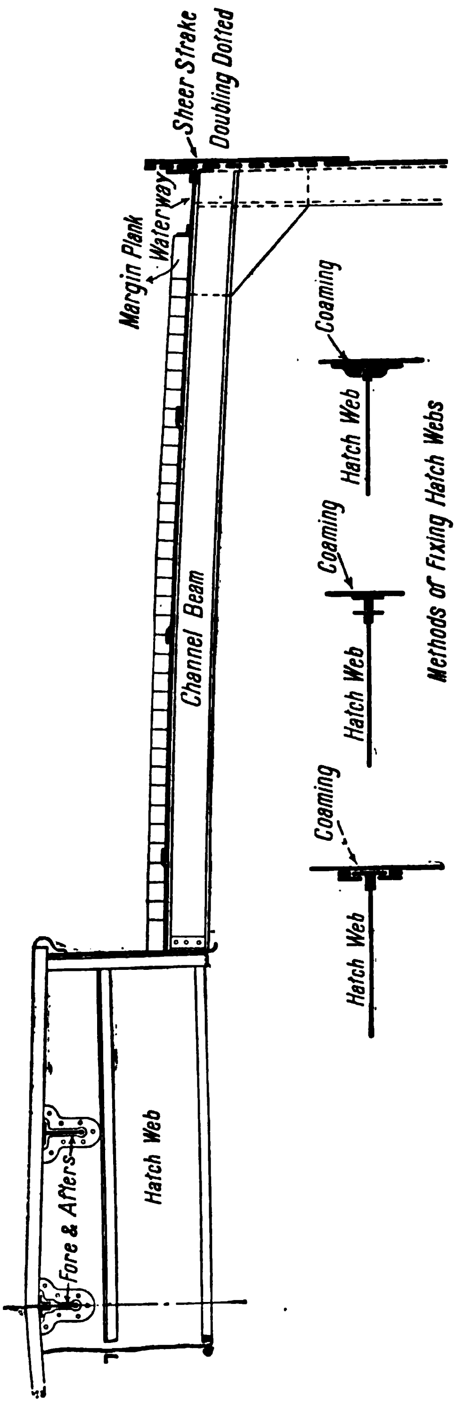

Sheer Strake
Doubling Dotted
Margin Plank
Waterway
Coaming
Hatch Web
Coaming
Hatch Web
Coaming
Hatch Web
Methods of Fixing Hatch Webs
Channel Beam
Hatch Web
Fore & Afters

FIG. 115.—Section through Hatchway, showing Hatch Webs and Slides, Channel Beam Knees, and Sheer Strake Doubling.

than three-fourths of the length of the midship beam. The reasonableness of this is easily explained. The shorter a beam or strut is made, preserving the same depth and thickness, the more rigidity does it possess, and the more resistance it offers to buckling. Hence the shorter end beams may be reduced $\frac{1}{20}$th in. in thickness, and still retain comparatively the efficiency of the beams at amidships.

Before leaving the upper deck beams, we may note that had the vessel been of larger type, and channel bar beams been adopted, the knees would generally be formed of bracket plates, and would be constructed as shown in fig. 115, the bulb being, of course, substituted by the lower flange of the channel bar. In all other respects the knee formation would be as usual.

Turning to the forecastle (see fig. 46) we see that the beams consist of a bulb plate and two angles fitted to alternate frames. The knee to the bulb plate is made as described in figs. 111, 112, or 113. In the fore peak, the beams are similar to the forecastle beams. The plan in fig. 112 shows how the two beam angles fit against the frame and reverse frame.

The widely-spaced hold beams, as shown in the midship section, fig. 10, consist of bulb plates with two top angles and a covering plate. The larger flanges of the angle bars are placed horizontally, which necessitates that the covering plate be of the same width. The knee is formed like all other bulb plate beam knees.

The hold beams might have been as shown in fig. 116, in which case the knee may be either welded or bracketed.

Against the bulkheads we observe (fig. 46) that what are called semi-box beams are fitted. Fig. 117 will show more clearly how this strong beam is composed.

Semi-box beams are principally intended to act as stiffening to the bulkheads. We shall again refer to these bulkhead stiffeners when dealing with bulkheads. Suffice it for the present to say that the bulb plate knee is made by one of the methods previously described.

On coming to the engine space, however, we find a number of extra strong through beams, which are continuous from side to side of the vessel. These are specially necessary when we remember that a large number of the ordinary beams are stopped in the way of the engine opening—these strong beams in some measure compensating for the loss of transverse strength. They consist mostly of bulb plates with four angles. The knees are of the usual construction. In elevation, the beam appears as shown in fig. 116, the plan being similar to fig. 112.

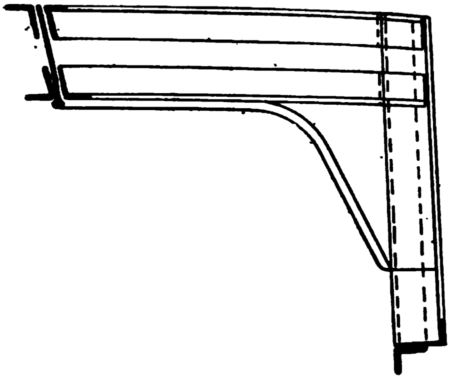


Fig. 116.—Strong Beam with Turned Knee.

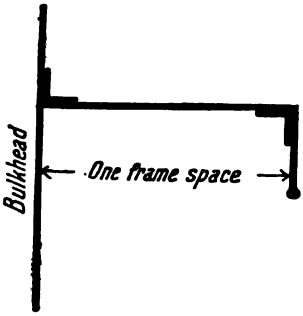


Fig. 117.—Semi-box Beam.

Sometimes two of these strong beams are fitted upon adjacent frames, and combined by plating them over—see strong beams in figs. 46, 47, and 49. We observe in the profile, fig. 46, that a steel deck is fitted all fore and aft to the upper deck. According to Lloyd's Rules, this vessel does not require more than a steel deck for half length amidships for structural purposes. Had the upper deck been sheathed with wood, the steel deck could have been gradually tapered off from the half length amidships, and the subsequent beams might have been of stronger section, and spaced upon alternate frames. However, the usual practice for cargo vessels has been followed in this case, and the steel deck made continuous all fore and aft, and unsheathed with wood. In many respects, this is preferable in cargo vessels.

When beams under wood decks are of tee bar, the knees are usually formed of bracket plates riveted on as for plain angles. When they consist of bulb plate and two angles, the knee is formed as already illustrated (see figs. 111, 112, and 113). When the beam is of butterly bulb section, the knee is usually made as shown in fig. 118.

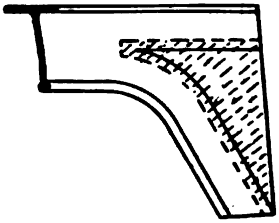


FIG. 118.—Butterly Bulb Welded Knee.

The extremities of the beam are cut through the middle of the depth, and the lower part is turned down. A piece of plate is then welded into the space completing the knee form. Bracket knees might have been adopted, in which case the bulb would have to be chipped off one side. When steel decks are laid upon beams to alternate frames, beams of smaller section should be fitted to every frame at the sides of all hatchways and engine and boiler openings.

Lloyd's Rules give the following table for number and size of rivets in beam knees :—

Depth of Knee.	No. of Rivets.	Diameter of Rivets.
Under 17 inches,	4	$\frac{5}{8}$ of an inch.
17 and under 21	5	$\frac{3}{4}$,, ,,
21 ,, ,, 24	5	$\frac{7}{8}$,, ,,
24 ,, ,, 28	6	,, ,, ,,
28 ,, ,, 32	7	,, ,, ,,
32 ,, ,, 36	8	,, ,, ,,
36 ,, ,, 40	9	,, ,, ,,

The following beam knees should be at least three times the depth of the beam :—

1. In all steamers or sailing ships having one tier of beams.
2. To all beams on deep framing or web frames.
3. To all beams on deep tanks, peak tanks, or other water-ballast tanks.
4. To all beams of over 50 ft. in length.

Pillars.

A variety of kinds of bar iron or steel may be used to perform the tie and strut functions of pillars in ships (between decks and floors), and thus in addition to the plain round bar of circular section which is most commonly used, tee bars either single or double, fitted back to back, channel bar single or double, and iron of I section, are now frequently adopted. One of the most recent types of ship pillars is made of stout steel plates bent into circular form and riveted like a mast. These, as we shall see, are fitted in combination with other structural features, to dispense with the numerous round iron pillars ordinarily required.

Ordinary Round Iron Pillars.—Round iron pillars are made of malleable iron, and may be either solid or hollow. Comparing sectional area with sectional area, the hollow pillar is stronger and much more efficient than the solid one, though it has the objection of occupying more space, and being more costly to produce. The heads and heels of hollow pillars are solid.

According to Lloyd's requirements, all beams upon alternate frames (when the frames are spaced to rule) for at least three-fourths of the vessel's length amidships should be pillared. The beams for the remaining one-eighth length at each end need only have pillars to beams upon every fourth frame. The pillars should be placed, as far as practicable, in the middle line of the vessel. In vessels with several decks or tiers of beams, in order that the pillars develop their full efficiency, they should extend from keelson or tank top to the upper deck, as nearly as possible in a vertical line, so as to form a continuous tie or strut.

The foregoing are only general rules, for it is impossible to rigidly follow them throughout the length of the vessel from stem to stern. For instance, in the engine and boiler spaces, such an arrangement is necessarily greatly interrupted, and stanchions have to be fitted where convenient. Again, in way of all hatches in the midde of the deck, the stanchions are placed on each side of the hatchway, generally somewhat more widely spaced (about six frames), as the deck has now two supports instead of one at the middle line. Under all permanent heavy deck weights, such as windlass, capstan, winches, deck houses, etc., additional pillars should be introduced, two or more generally being placed athwartships under such deck weights. Where hold beams are dispensed with—compensation in some form or other being introduced—the lower pillars, obviously, should be of greater diameter than would have been necessary had the hold beams been fitted, the greater length reducing the resistance to buckling, and increasing the danger of collapse.

In vessels of great breadth, naturally the beams require support between the ship's side and the centre line pillars, hence quarter pillars are introduced. (See fig. 48.) Lloyd's Rules require that for steam vessels of over 43 ft. and under 55 ft. in breadth, the quarter pillars be fitted to beams upon every fourth frame for half the vessel's length amidships, in addition to the centre line pillars.

In pillaring a vessel, it is of the greatest importance to see that the heads and heels are efficiently constructed. Indeed, owing to the bad formation of the heads especially of some pillars, they never get the chance, as it were, *of developing their fullest efficiency.* In the making of pillar heads especially—which, by the way, together with the feet, are made separately, and afterwards welded on to the pillar bar—the formation should be such that any thrust or compressive stress will be transmitted directly through the middle of the pillar, and not on one side (see figs. 119, 120, etc.); and the pillar head should bear hard against the beam or girder, so that the stress is borne by the material in the pillar, and not the rivets only. With such a formation of heads and feet, the rivets are only subject to stress when tensile strains are endured, *i.e.* when the pillar becomes a tie.

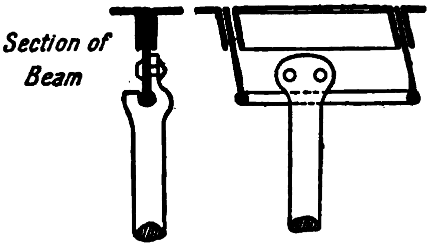

Section of Beam

FIG. 119.—Connection of Pillar Head to Bulb Plate Beam.

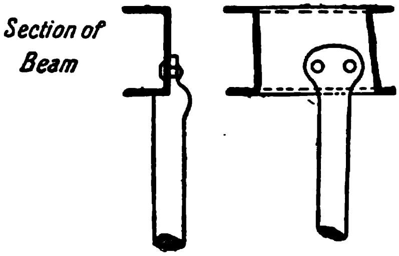

Section of Beam

FIG. 120.—Connection of Pillar Head to Channel Bar Beam.

A great point to be kept in view in the pillaring of a ship is to see that the pillars do not act as *independent* struts or ties, but that they *distribute* their efficacy as far as practicable. Thus, especially in the case of vessels with steel decks, and bulb angle beams to every frame, to fix the pillar from the tank top or keelson to this comparatively flexible beam itself, would

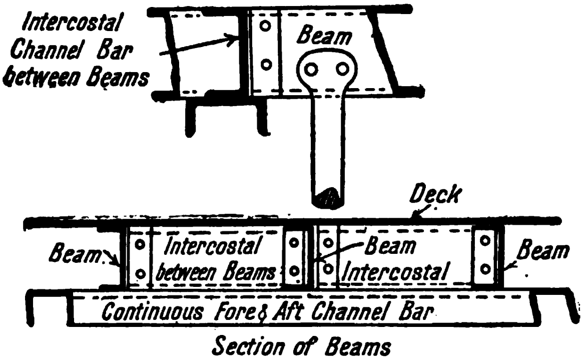

Intercostal Channel Bar between Beams
Beam
Deck
Beam
Intercostal between Beams
Beam Intercostal
Beam
Continuous Fore & Aft Channel Bar
Section of Beams

FIG. 121.—Showing an excellent method of supporting Steel Decks in combination with Pillars.

produce the tendency, when the pillar is subject to a compressive stress, to bulge up the deck in way of the pillar. To obviate this, a common practice is to fit a tee bar, or two angles back to back, to the underside of plain or bulb angle beams, and make the connection by fixing a short lug upon the bottom of the beam, as shown in figs. 122, 124, 125, and 49. The pillar heads are then riveted to these fore and aft bars, under the alternate beams according to rule. The formation of pillar heads is shown in figs. 119 to 127. By means of the continuous longitudinal beam tie bars just referred to (figs. 121, 122, 124, 125, 127), the work done by the pillars is distributed to all the beams, instead of only to those under which the pillars are fixed. Similarly, where channel bar beams are fitted to every frame, the usual practice again is to tie the beams together, so as to distribute the pillar support. This is sometimes done by fitting a continuous channel bar to the under side of these beams (fig. 121). In this case, the pillars may be fitted alternately to one and the other of the continuous channel bar flanges on the under side of the beams, but it is preferable to attach the pillar head directly to the channel beam. As the section in fig. 120 points out, a much better supporting surface is obtained than could be got by riveting the pillar head to one of the flanges of the continuous channel tie bar. An even better system than this is seen in fig. 121, where, in addition to this continuous channel tie bar, intercostal channel bars are fitted between the beams, to which, by means of lugs, they are riveted; and also in fig. 127, where, in addition to the double angles on the under side of the beams, intercostal plates are fitted between the beams, and riveted to the deck. Such a system of fitting a substantial girder to beams and deck, especially if bracketed to the bulkheads at the end of each hold compartment, affords great support and stiffness to the deck, and

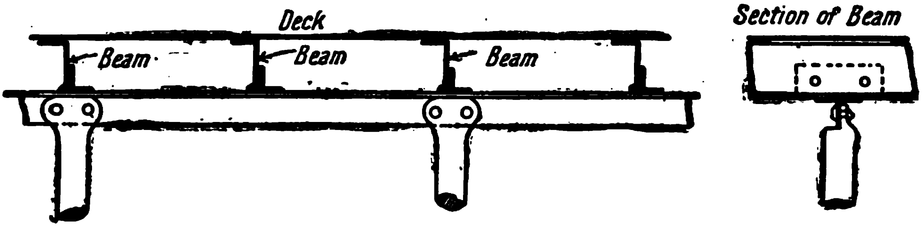


FIG. 122.—Connection of Pillar Heads to a fore and aft Tee-bar tie under Beams.

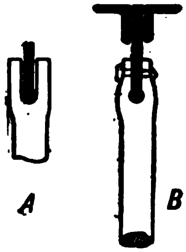


FIG. 123.—Another form of Pillar Head.

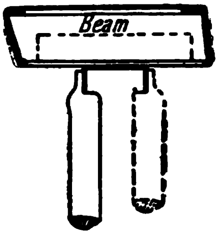


FIG. 124.—Arrangement for fitting Hold Shifting Boards between Pillars.

permits of the hold pillars (if of increased sectional area) being spaced much more widely than is usual. The advantage of such an arrangement from a stowage of cargo point of view is apparent. This applies equally to fig. 121.

The formation of pillar heads for channel beams is shown in figs. 120 and 121. Where, however, the beams are fitted on alternate frames, and are therefore much more rigid owing to their greater depth and sectional area, than would be the case for beams on every frame, it is usual to fit the pillar heads directly on to the beams, no continuous tie being fitted to the under side of such deep beams. (See figs. 119 and 120.) When shifting boards must of necessity be fitted down the middle of a hold to prevent cargo moving, the common practice is to place them between round iron pillars arranged as shown in fig. 124. In this case we have a continuous channel tie on the under side of the beams

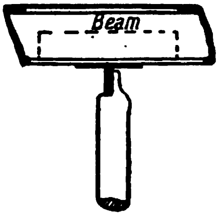


Fig. 125.—Double Angle Beam Tie, and Pillar-head Connection.

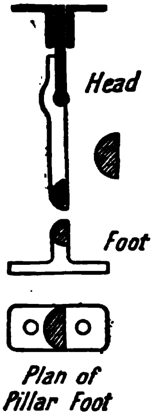


Fig. 126.—Pillar in Cabins.

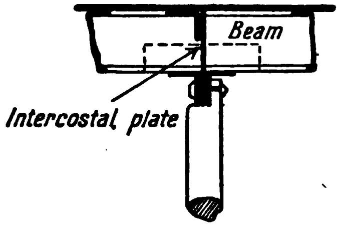


Fig. 127.—Another excellent method of supporting Steel Decks in conjunction with Pillars.

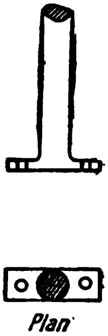


Fig. 128.—Ordinary Pillar Foot.

to which the alternate pillars are fitted to first one and then the other flange. Instead of the channel bar, two angle bars are sometimes used for the same purpose.

All pillar heads, such as those we have just described, should be connected by at least two rivets. A pillar head not very commonly adopted, but which requires only one rivet, is seen in fig. 123. The head is formed as shown in A. This head, on being heated and placed under the beam, is closed up as in B, and secured by one rivet. Where pillars are required to be portable, the heads are fastened by means of nut and screw bolts instead of rivets.

The formation of pillar feet, connected to a centre keelson standing on ordinary floors, is shown in elevation and plan in fig. 128. The connection here is by means of two rivets. Where, however, the pillar feet come over the centre through-plate in a vessel with a double bottom, the feet are formed and connected as in figs. 129 and 130. In fig. 129 a socket is formed for the pillar foot, either between two flange plates, or two angle bars riveted on to a base plate through which the connection is made to the tank top. In the alternative method, fig. 130, the frame foot is connected to a piece of tee bar which is riveted through the tank top plating and upper bars of the centre keelson. The pillar feet in a 'tween decks where a steel deck is laid, should be riveted through the deck plating and the beam. But a better arrangement is to fit the feet on to a short piece of tee bar, long enough to take three rivets, somewhat similar to the sketch in fig. 130. Where, however, no steel deck is laid, and the beams are upon alternate frames, the pillar feet may be formed as in fig. 128, and attached directly to the beam. Or better still, by fitting a continuous tie bar, or two angle bars riveted back to back, a more satisfactory distribution of the work of the pillar is obtained. These angle bars, if made large enough in their horizontal flanges, will form a substitute for the tie plates which in any

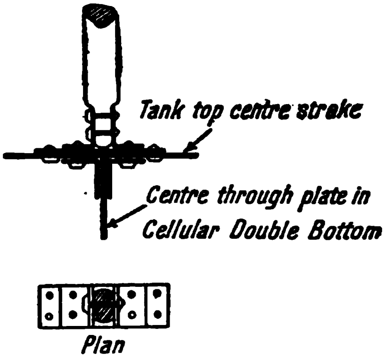


FIG. 129.—Pillar Foot on Inner Plating of Double Bottoms.

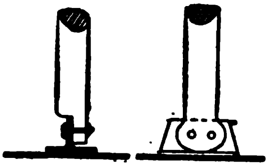


FIG. 130.—Showing connection of Pillar Feet to Steel Decks, or Inner Plating of Double Bottoms.

case would be necessary upon beams on alternate frames where no steel deck is laid. Where pillars are required to be portable, which is often necessary at hatch sides, the feet may be made in any one of the three ways shown in figs. 131, 132 (A and B).

Fig. 131 shows the pillar foot dropped into a cast-iron ring, which is riveted to the deck or tank top plating as the case may be. A half inch or five-eighths nut and screw bolt is passed through the cast-iron ring and pillar foot as shown. Fig. 132, B, shows the pillar foot placed in a horseshoe angle bar, and is kept in position by a preventive nut and screw bolt. In this method, the pillar only performs the function of a strut. As shown in the diagram 132, A, the foot of the pillar is permanently riveted, the upper part only being portable, with a nut and screw bolt means of connection as shown.*

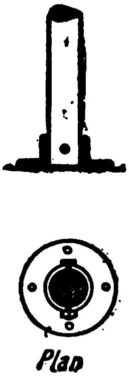


Fig. 131.—Portable Pillar Foot.

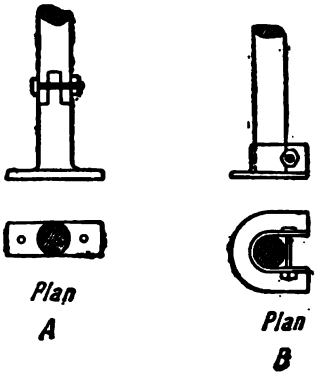


Fig. 132.—Portable Pillars. Arrangement of Feet.

The heads and heels of all ordinary pillars fitted in cargo vessels should be connected to the structure by at least two well formed rivets. But those fitted in deep water-ballast tanks should be connected by means of three rivets.

Channel and Tee Bar Pillars.—Where pillars are constructed of tee bars or channel bars (either single or double), or of I section, they are connected to the beams at their upper extremities, and to the tank top at their lower extremities, by means of bracket plates. (See figs. 64, 67, 70, 73, and 74.)

Large Round Plate Pillars—substituting centre line hold and quarter pillars—have already been dealt with in Chapter VI. Section 2, 'Some New Features in Modern Shipbuilding.' (See figs. 72, 73, and 74.)

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* These portable pillars are not as efficient as well formed fixed stanchions, but as only very few are usually required (generally at the side of hatchways), no serious objection need be offered to them.

When cabins are fitted in a 'tween decks, the ordinary round pillar is sometimes objectionable, and in many cases half round or flat iron stanchions, as in fig. 126, are substituted.

Keelsons and Stringers.

Keelsons.—The most important keelson in the ship is the centre keelson, and although, according to the particular mode of construction adopted, it varies considerably in form, its function is always the same, viz., to afford longitudinal strength along the bottom of the ship. The centre through-plate keelson and side keelsons, in vessels with double bottoms, have been referred to on several occasions and fully described already. (See figs. 48, 58, etc.)

Fig. 133, A and B, illustrate what are known as centre keelsons standing upon ordinary floors, the vessel in the diagrams having a bar keel. The principal parts of the keelson, A, are a deep vertical plate with two large angles on the bottom connected to the reverse frames and the lug piece shown; and, on the upper edge, two similar large angles with a flat plate, known as a rider plate, covering the full width of the top flanges. The large keelson angles have one flange exceptionally large, while the other is considerably smaller. The large flanges are arranged vertically for the bottom bars, and horizontally for the top bars. The butts of both centre plate and rider plate should be either strapped or overlapped, and treble riveted. The butts of the angle bars should be connected by bosom pieces with at least three rivets on each side of the butt. The butts of vertical plate, rider plate, and angles, should be kept as clear from each other as practicable. The centre keelson in B, fig. 133, is identical with A, with the exception that being for a larger vessel, a thick foundation plate is riveted to the floors immediately under the keelson to which the bottom angles are connected.

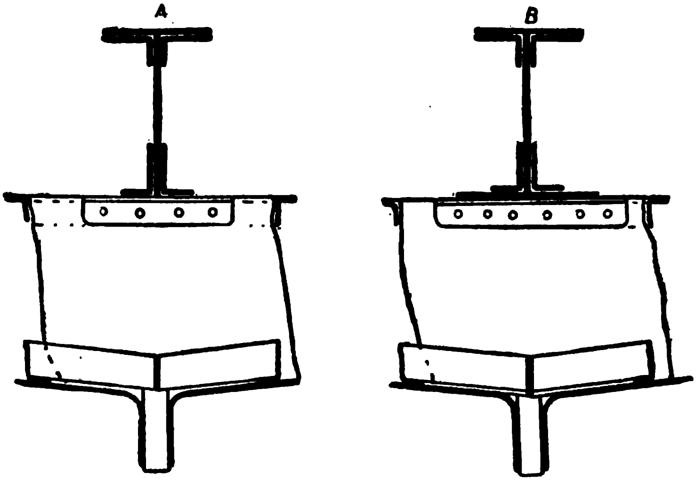
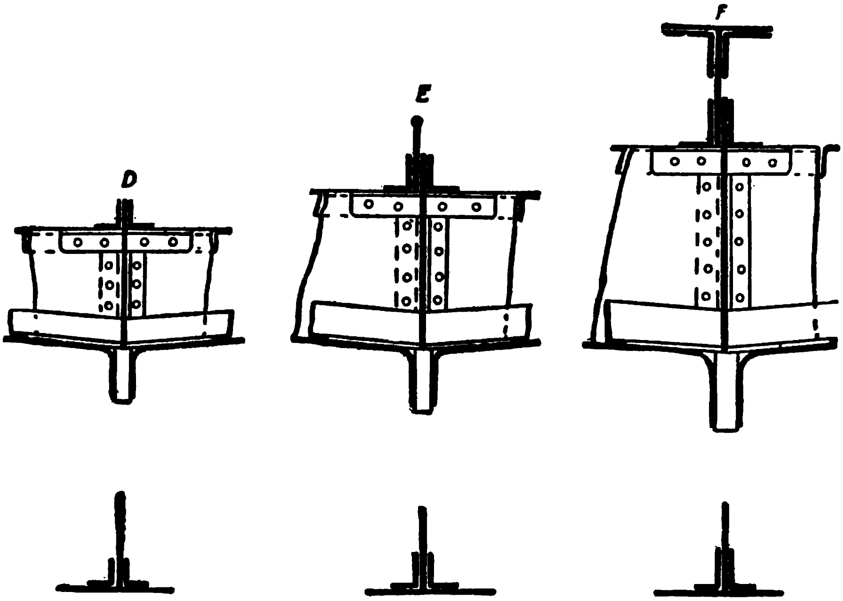


FIG. 133.—Centre Keelsons standing upon Ordinary Floors.

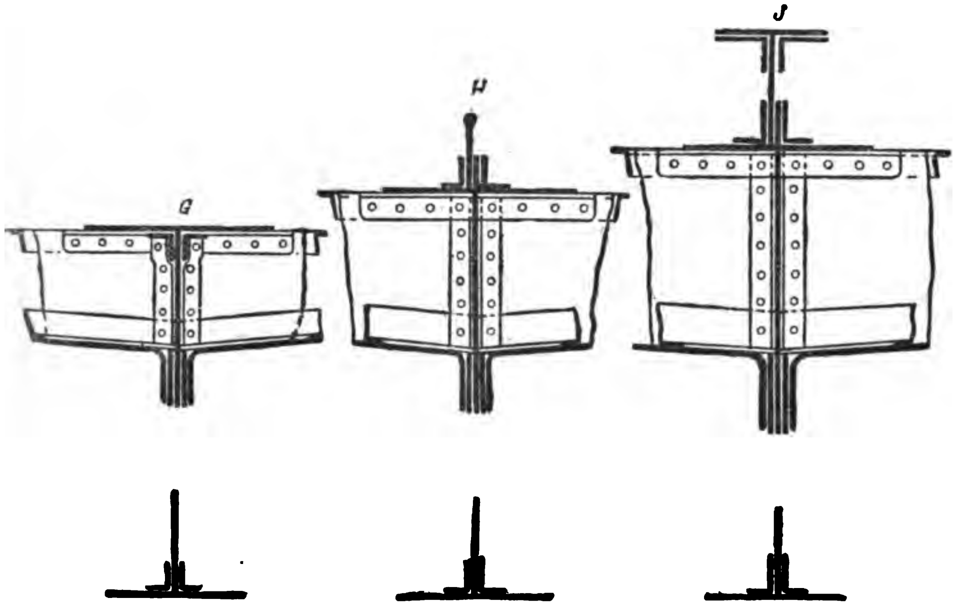
Fig. 134, D, E, F, illustrates another type of centre keelson, known as a middle line intercostal keelson. As the diagrams show, the vessel has ordinary floors and a bar keel. The keelson in D, which is for a very small ship, has two continuous angles on the top of the floors, with intercostal plates fitted between the floors extending from the top of the keel to the top of the keelson angles. The intercostal plates are connected to the floors by single angles as shown. Figs. E and F are similar keelsons for vessels of larger size. The intercostal plate in each case extends to the top of the lower keelson angles.

Fig. 135, G, H, and J, illustrates the centre through-plate keelson in vessels having side bar keels. Here, again, the floors are of the ordinary type. In G, the centre through-plate extends from the bottom of the keel to the top of the floors. Along its upper edge, and riveted to the floors, is a broad thick plate, connected to the centre through-plate by the two large angles shown on its upper edge. It will be seen how admirably this plate binds both floors and keelson together. Fig. H, which is for a larger vessel, shows the centre through-plate extending to the top of the keelson angles. The foundation plate upon the floors under the keelson angles is necessarily in two pieces, one on each side of the centre through-plate. Fig. J is identical with fig. H, excepting that being for a still larger vessel, the part of the keelson above the floors is somewhat modified.



Showing Intercostal Plates fitted upon Flat Plate Keels.
Fig. 134.—Intercostal Centre Keelsons.

Side Keelsons (fig. 136).—All vessels should have keelsons upon the floors at the lower turn of the bilge. These may vary in section as shown in fig. 136, P, Q, M. P is two plain angles fitted back to back. Q is the same as P with a bulb plate between. M is the same as Q, excepting that in addition to the bulb plate, an intercostal plate is fitted from the top of the angles to the bottom of the floors, and connected to the shell by another angle bar as illustrated in fig. L. The bulbs and intercostals are often extra strength introduced on account of a vessel's extreme proportions. Between the centre keelson and the bilge in very small vessels, a thin plate is fitted intercostally between the floors to which it is connected. The principal function of this plate is to check the wash of bilge water when the vessel is rolling. Hence it is called a wash plate



Showing Centre Through-plates fitted upon Flat Plate Keels.
FIG. 135.—Centre Through-plate Keelsons for Vessels having Side Bar Keels.

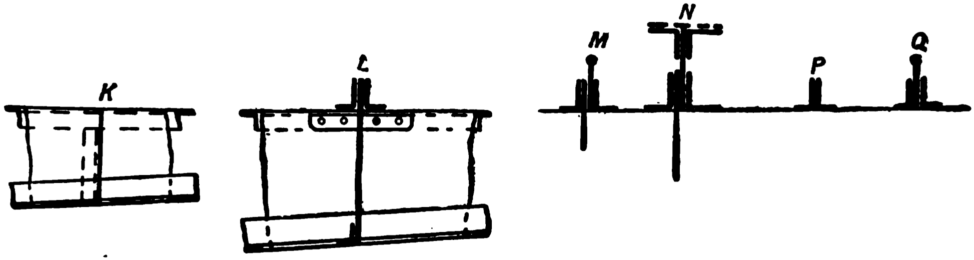


FIG. 136.—Side Keelsons.

(see K). In larger vessels a double angle side keelson is required extending across the top edge of the floors, with sometimes both a bulb and an intercostal plate between them (fig., L and M). In still larger vessels, or where the proportions are very extreme, a side keelson with an intercostal plate, as shown in N, is sometimes required.

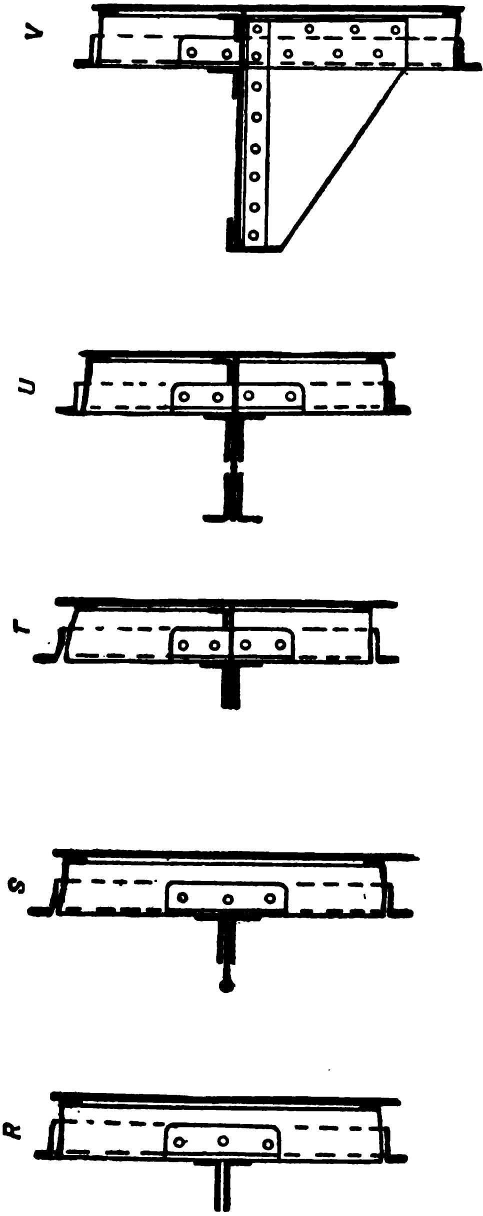


Fig. 137.—Forms of Side Stringers.

In all cases wherever centre, side, or bilge keelson angles, or horizontal plates, pass over the floors, the connection is made by short lug bars in addition to the ordinary reverse frames.

Stringers.—Stringers, in many respects, are very similar to keelsons.

Fig. 137, R, S, T, U, V, illustrates a number of types which are regulated by the depth and proportions of the vessel. As already pointed out for keelsons, angle lugs are again required in addition to the reversed frames, in order to get a good connection to the transverse framing. Stringers for vessels with deep frames are illustrated in figs. 12 and 48. Keelsons and stringers may be carried uninterruptedly through all the bulkheads, in which case, well-formed angle collars are necessary in order to ensure watertightness (see fig. 138, F.) Where the stringers are cut at the bulkheads, which is the simpler way of obtaining watertightness, the continuity of their strength is maintained by fitting large bracket plates.

Fig. 137, A, illustrates a side stringer such as is shown in the midship section of fig. 48, cut at the bulkheads and connected by large brackets, which extend to the heel of the bulb angles forming the stringers.

Stringers and keelsons should be carried as far forward and aft as practicable, and their ends should be connected to a breast hook—a horizontal plate binding the two sides of the vessel together.

Bulkheads.

Steel and iron bulkheads are walls of plating extending transversely from side to side, or longitudinally, throughout the whole or part of the length of a vessel. They are valuable as a means of dividing the large volume contained in the hull of a ship into a number of separate compartments, and in entirely shutting off the engine and boiler spaces from the hold spaces, a feature of very great importance where inflammable cargo is carried in the adjoining compartments.

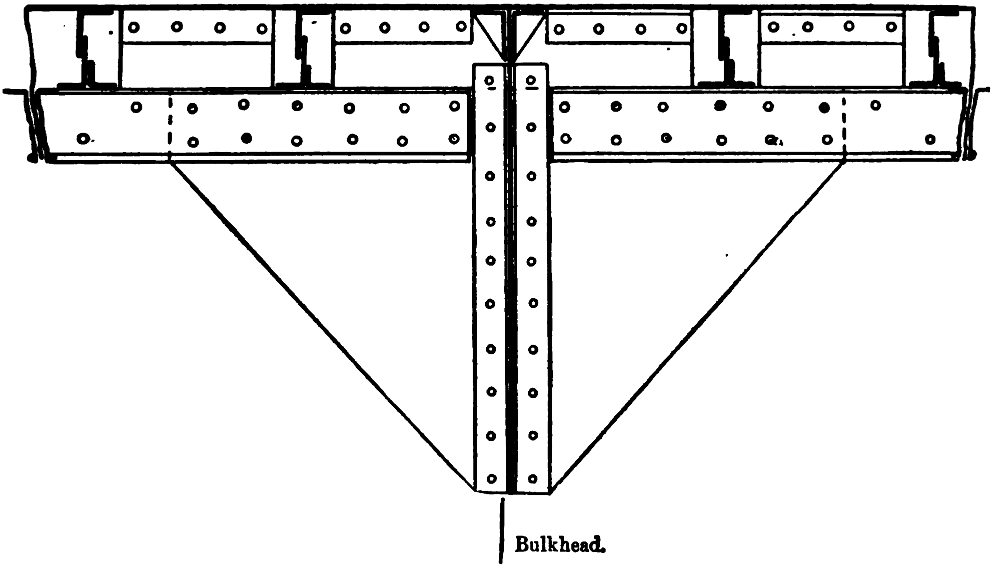


FIG. 137, A.—Stringer cut at a Bulkhead, and connected by large Brackets.

But their principal function lies in affording structural strength and safety in the event of the shell being perforated, and water finding access. Long shallow vessels are particularly liable to evince longitudinal weakness. In such vessels, great additional strength and stiffness is obtained by fitting a continuous longitudinal bulkhead all fore and aft down the middle of the hull and connecting it to, or making it form part of, a centre keelson on its lower extremity, and attaching it to the deck at its upper edge.

Transverse bulkheads afford great support to both the longitudinal and the transverse framing of a vessel, and contribute in a large measure to the general strength. When transverse bulkheads are well constructed, and stiffened, and made perfectly watertight, they may render immense service in case of collision or perforation of the shell plating by confining the water to one of the compartments into which they divide the hull. They must, therefore, be securely connected to the shell plating, decks, and bottom of the vessel, and, in addition, the plating must be of sufficient thickness, and stiffened and supported in such a manner as to withstand the pressure of water which would come upon it in the event of such a compartment being perforated and flooded. A longitudinal bulkhead, while it may provide valuable and necessary strength to the hull, may also be a source of danger if made watertight, excepting in the case of vessels carrying liquid cargoes, for in the event of a compartment on one side of such a bulkhead becoming flooded, the loss of buoyancy may produce a positive danger, which would not have existed had the water been able to fill the compartment from one side of the vessel to the other. It is therefore advisable, under some circumstances, to so construct a longitudinal bulkhead that water could find ready access through it.

All vessels classed at Lloyd's are required to have a certain number of transverse bulkheads, which number depends in steamers upon the length. The rules require that all screw steamers have at least four watertight bulkheads, one at each end of the engine and boiler space, and one at a reasonable distance from each end of the vessel.

The necessity and importance of these bulkheads is fairly obvious. The importance of having the engine and boiler spaces thoroughly isolated from the remaining portions of the hull has already been referred to. The fore-end of vessels being likely to suffer most severely in the event of collision, and, in addition, being specially subject to the thumping action of the waves in steaming against head seas, as well as the tendency to pant when driven at considerable speed, even in smooth water, all clearly show the necessity of a watertight bulkhead at a moderate distance from the stem, which, the rule states, should not be less than half the vessel's moulded breadth in order to safeguard the vessel should leakage occur from any of these causes.

At the after end of the vessel, especially in very large ones, we have an enormously heavy stern frame attached by means of long rivets to what are, in comparison, thin plates composing the shell, and which, in addition, is subject to considerable vibration caused by the propeller, especially when racing in heavy weather. Again, the breaking of a tail shaft often fractures the stern tube and hence the possibility of leakage, and the necessity of a watertight bulkhead at a reasonable distance from the stern post. Where the shaft passes through this bulkhead, the watertightness is assured by fitting a stuffing box.

When the length is 280 ft. and above in steamers, an additional bulkhead is required by Lloyd's midway between the collision and the foremost engine space bulkheads, and when the length reaches 330 ft. and over, another bulkhead is required in the after hold, situated therefore between the aftermost bulkhead in the vessel and the after engine room bulkhead.* These additional bulkheads not only assist in stiffening the framing of the vessel, but they improve the chances of the vessel remaining afloat in the event of one of these compartments becoming flooded. All transverse bulkheads in one, two, and three decked vessels should extend to the height of the upper deck, and in spar deck vessels to the height of the spar deck. In the case of awning deck vessels, all the bulkheads should extend to the height of the main deck with the exception of the collision bulkhead, which should extend to the awning deck.†

As we have pointed out, the fore end of the vessel being the most vulnerable, and the loss of buoyancy at the extreme ends of a vessel through perforation of the shell plating producing greater change of trim than the loss of as much and even more buoyancy nearer amidships, the necessity of continuing the collision bulkhead, even in an awning deck vessel, to the weather deck, will be clear. To carry a watertight bulkhead in a direct uninterrupted vertical plane from the floors to the prescribed height, is not always convenient nor is it absolutely necessary. It may be recessed or stepped backwards or forwards at some place in its height, and then carried to the required deck. No objection can reasonably be lodged against this so long as the workmanship is thoroughly efficient, and the strength and watertightness maintained.

In sailing vessels, only the collision bulkhead is required by Lloyd's, though many owners prefer to introduce additional bulkheads for the sake of the improved conditions of safety, and the convenience of having the hold space divided into separate compartments for the stowage of cargo.

In arranging the plates of a bulkhead, they are disposed either with their lengths vertical or horizontal. Fig. 138 is a sketch of a bulkhead with the plates arranged horizontally. As the figure shows, the vessel has two steel decks, and as the continuity of a steel deck is vastly more important than the continuity of the bulkhead, the deck suffers no interruption, but the bulkhead is severed at the lower steel deck, and continued again in the 'tween decks.

A watertight bulkhead is connected to the shell plating by means of double angle bars of the size of the frames between which angles the bulkhead plating is fitted. (See horizontal section of bulkheads, fig. 138, A and B.) As the watertightness must be maintained from lower to upper extremity, a connection to the steel decks is usually made by means of double angle bars of about the size required for reversed frames. (See E, C, and K, fig 138.) Should the vessel have a double bottom, the connection to the tank top is also usually made by means of double angles of the size already mentioned, D, C, K, fig. 138. While the overlapping of the edges and butts of the plates gives a certain amount of stiffness to the area of plating, yet this is totally inadequate to provide the strength required in carrying even bulk cargoes, such as grain, much less to withstand the pressure which would accrue, owing to a head of water, in the event of a hold space becoming flooded to any considerable extent. An intelligent arrangement, therefore, of well-disposed stiffeners is necessary. Lloyd's requirements for the stiffening of transverse bulkheads are as follows:—On one side of the bulkhead the stiffeners are angle bars of the size of the frames spaced not more than 30 in. apart. If the vessel is built with ordinary floors, these stiffeners should be continued well down over the floor plate. (See E, fig. 138.) If the vessel have a double bottom, these stiffeners should be connected to the inner bottom plating by means of plate brackets (D, K, fig. 138.) Additional vertical stiffening is given to all bulkheads of large breadth in the form of webs of plating extending from the centre keelson or top of floors, or from the tank top in vessels with double bottoms to the height of the lowermost tier of beams (A and C, fig. 138). When the bulkhead is 36 ft. and under 45 ft. in breadth, one such vertical web stiffener is required, and, in the case of vessels with ordinary floors, would be riveted at its lower extremity to the top of the centre keelson. When the breadth of the bulkhead is 45 and under 55 ft., two such vertical webs are required. Bulkheads of 55 and under 60 ft. in breadth require three vertical webs. In order to support the vertical stiffeners, and to give additional rigidity and strength to the bulkhead, horizontal stiffeners are fitted to the other side of the bulkhead, and spaced below the lowermost laid deck, about 48 in. apart. These stiffeners, in all vessels of less than 40 ft. in breadth, may be of angle bars of the size of the main frames, but when the bulkhead is of 40 ft. breadth and above, the horizontal stiffeners should be of bulb angles of at least the size required for a steel or iron deck fitted to the same vessel.

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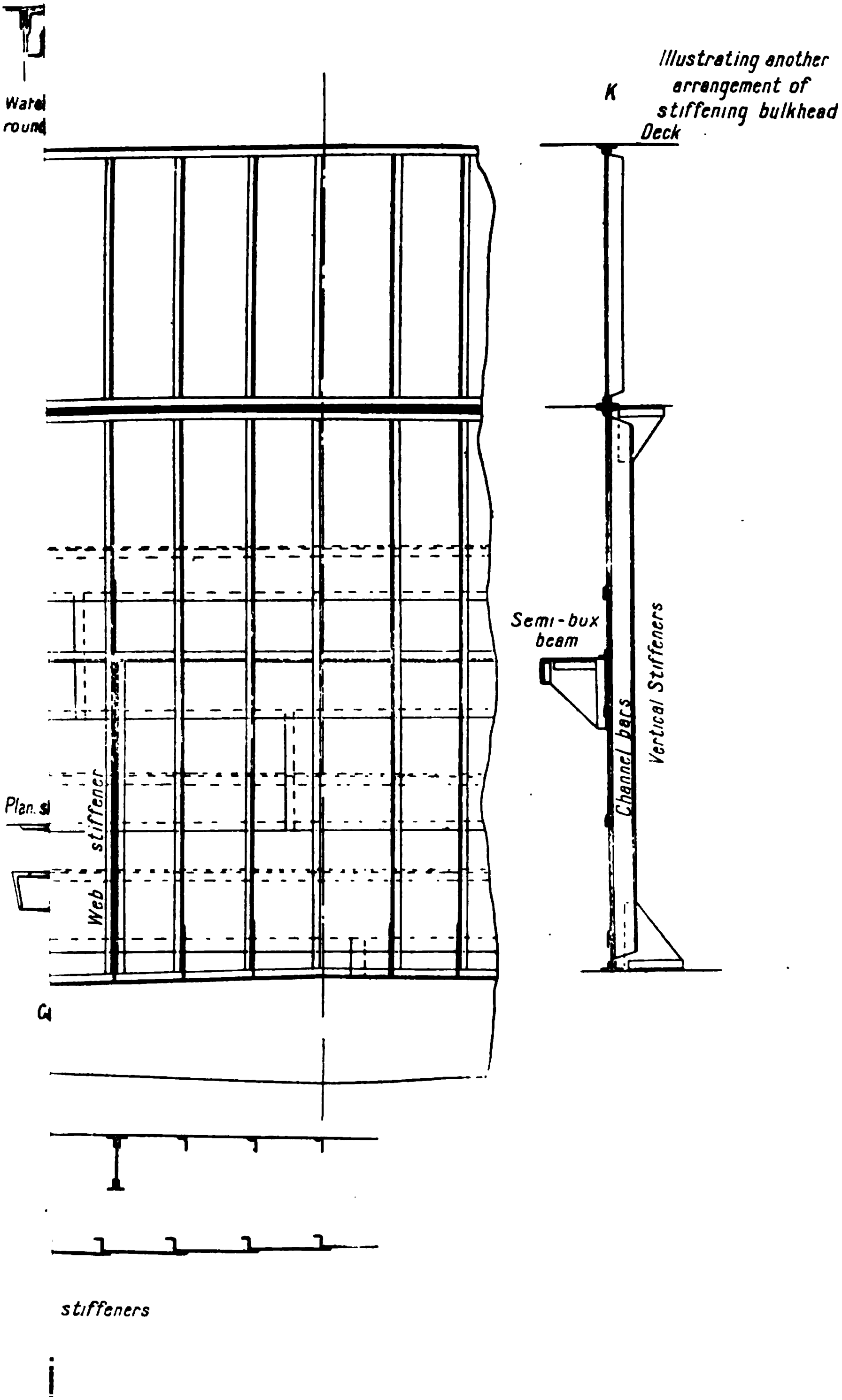
* Vessels over 400 ft. require 7 bulkheads.
" " 470 " " 8 "
" " 540 " " 9 "

† In awning deck and shelter deck vessels, partial bulkheads or web frames for the support of the topsides should be fitted in the 'tween decks immediately above the main bulkheads.

These bulb angle stiffeners should be well connected to the vessel's side by means of plate brackets.

In all vessels requiring two or more decks, where the lowermost deck has been dispensed with by compensation in some form or other, or when such a deck is not laid so as to give longitudinal support to the bulkhead, Lloyd's require that a semi-box beam, E, C, and K (see fig. 138), be fitted across the bulkhead where the lower deck would have afforded its support; or, if there be a side stringer in this vicinity, the semi-box beam may be fitted so that its ends may be attached to the stringer. The breadth of the semi-box beam is one frame space, and the bulb plate or channel bar or bulb angle forming the side of the beam away from the bulkhead should be connected to the frame upon which it comes by an efficient knee. (See also fig. 117.) The fore peak, as we have already noticed, being especially liable


Illustrating another arrangement of stiffening bulkhead
K
Deck
Wate
round
Semi-box beam
Vertical Stiffeners
Channel bars
Web stiffener
Plan. s
G
stiffeners

to damage, and the compartment to being flooded, special attention is always given to rendering this bulkhead thoroughly efficient under all circumstances of emergency. Hence, Lloyd's require that the horizontal stiffeners should be of bulb angle of the size of iron and steel deck beams, and connected to the vessel's sides by plate brackets. Where, however, the fore and after peaks are intended to carry water-ballast, and indeed in all deep tanks situated either at the ends of the vessel, or in the region of amidships, the vertical stiffeners on the bounding bulkheads should always be of bulb angles or channels of at least the size just mentioned (K, fig. 138). The stress upon these bulkheads is very severe when the tanks are full, but where, through neglect or carelessness, vessels are allowed to proceed to sea with these tanks only partially filled, the damage to the bulkhead may be enormous. (See sketches.)

Owing to the pressure of water upon a bulkhead in a flooded compartment being greater on the lower half than upon the upper, it is the practice to make the plating in the lower half $\frac{1}{16}$th or $\frac{1}{20}$th in. thicker than in the upper. The riveting of both lap edges and lap butts of bulkhead plating is usually made by a single row of rivets, excepting in the connection of the main bulkhead plating to the deep floor plate which forms the lower part of the bulkhead, in vessels with ordinary floors, and the coaming plate in vessels with double bottoms. (See fig. 138.) This latter connection should be made by a double row of rivets. The spacing of bulkhead rivets should be about 4 diameters apart from centre to centre. The rivet holes in the transverse flanges of the double angle bars connecting the bulkhead to the shell plating should also be about 4 diameters apart from centre to centre.

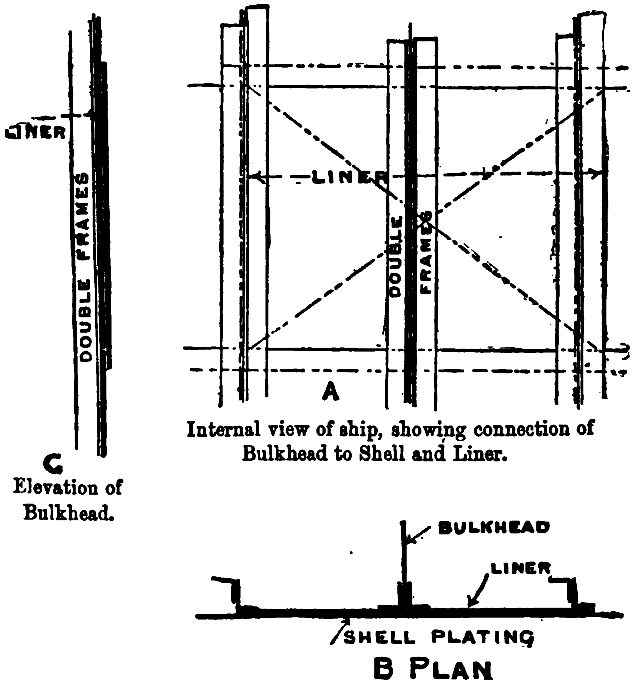
All bulkheads must be caulked to ensure watertightness. This, however, it is only necessary to do upon one side of the bulkhead.

In making the connection of the double angle bars round the bulkhead to the shell plating, the rivet holes in the fore and aft flange of that bar fitted upon that side of bulkhead which is caulked should be spaced about 4 to 4½ diameters apart. The rivet holes in the fore and aft flange of the other bar which is upon the other side of the bulkhead should be spaced to the ordinary spacing in frames, viz., 7 to 8 diameters apart.

As will be shown when we come to deal more particularly with shell plating, the most perforated transverse section of the shell is in way of the line of rivet holes, spaced, as we have stated, 4 to 4½ diameters apart on the caulked side of the bulkhead. Some compensation must therefore be made for this excessive weakening of the shell plating. This is done by fitting what are called bulkhead liners, or doubling plates.

The doubling plates are fitted in way of the outside strakes of shell plates only, and, it is needless to say, are on the inside of the plating. They may be either rectangular or of diamond shape. (See figs. 139 and 140.)

It will be noticed in fig. 139 that the liner extends from inner edge to inner edge of the adjacent inside strakes of plating, and in a fore and aft direction over two frame spaces from the heel of the first frame abaft the bulkhead to the toe of the first frame forward of the bulkhead. Fig. 140, showing the diamond-shaped liner, is so clear as to need no comment. The spacing of the rivets in these bulkhead liners is usually similar to that


LINER
DOUBLE FRAMES
C
LINER
DOUBLE FRAMES
A
BULKHEAD
LINER
SHELL PLATING
B PLAN

Internal view of ship, showing connection of Bulkhead to Shell and Liner.

Elevation of Bulkhead.

FIG. 139.—Connection of Bulkhead to Shell.

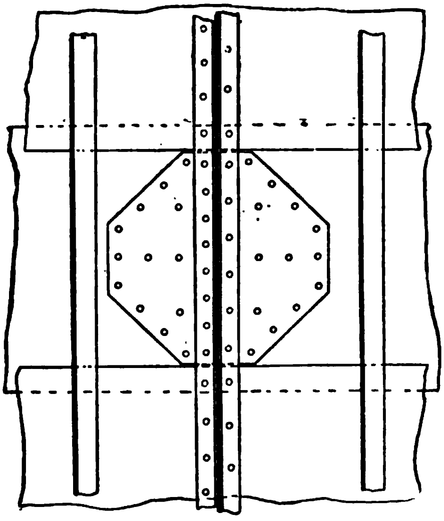


FIG. 140.—Bulkhead Diamond Liner.

illustrated in the sketch. By means of these doubling plates, fitted from gunwale to keel on the inside of all outside strakes of shell plating in vessels with ordinary floors, and from gunwale to tank side in vessels with a double bottom, the loss of strength caused by the severe perforation of the shell plating in way of the bulkhead is regained. In all cases, the collision and aftermost bulkheads should have their efficiency and watertightness tested by filling the fore and after peaks with water to the height of the load line. In order to detect more readily where the caulking is faulty, in the event of there being leakage, the collision bulkhead must be caulked upon the after side, and the aftermost bulkhead upon the fore side. This same rule applies to all bulkheads bounding deep water-ballast tanks, that is, the caulking should be upon that side of the bulkhead which is the outside of the tank. For other bulkheads, it is immaterial which side is caulked, but it is always the side upon which the rivets have been hammered up.

The usual forms of rivets adopted in bulkheads which are not exposed to view, and where appearance is of no moment, are the pan- and plug-head, with beat-up points, these being the most effective rivets for completely filling up the rivet holes, and obtaining watertight results. (See fig. 90.)

Where, however, the bulkheads are exposed to view upon one side, as in the engine room, for instance, it is more common to adopt the pan-head rivet, and to form a snap head on the other side, the snap head being on the exposed side of the bulkhead, or to use snap-head and snap-point rivets. This certainly gives a better appearance, but being formed by hand, the results are not always satisfactory from a watertight point of view. (See further remarks upon 'Rivets,' p. 167).

When a 'tween-deck bulkhead is stepped one or more frame spaces either backwards or forwards, which, by the way, is often done in collision bulkheads, great care should be taken to ensure that the flat at the break in the bulkhead is both well constructed and thoroughly watertight. This can be done by cutting the frames in way of this watertight flat, and running an angle bar continuously along the outer edge of the flat, connecting the flat to the shell plating, and preserving the strength of the transverse frames by connecting the upper frame legs to the watertight flat by means of plate brackets. (See 'tween decks, fig. 78.)

Another method is that of cutting the reverse bars in way of the flat, and doubling the frames for a length of about three feet to compensate for the loss of transverse strength, and joggling an angle bar round the frames throughout the length of the flat. (See fig. 138, L.)

Another method still, though one that is by no means extensively adopted, is to fit cast metal chocks in each frame space between the shell and the continuous angle bar on the inside of the frames. A space of about three-quarters of an inch round these chocks is filled with fine waste metal from drilling machines rusted with sal-ammoniac and thoroughly caulked.

In arranging the stiffeners of bulkheads bounding deep water-ballast tanks, the horizontal stiffeners are often dispensed with entirely, with the exception, sometimes, of a semi-box beam stiffener, and instead, stronger vertical stiffeners are kneed to the deck at the top, and to the tank top at the bottom when the double bottom is fitted. (See K, fig. 138.) While the foregoing remarks upon bulkheads are in accordance with the usual practice of plating and stiffening, in recent years other methods have been to some extent adopted. Fig. 138, B, is a horizontal sectional plan, showing a system of flanging the alternate vertical strakes of plating, as shown, and by this means the plating is made to form its own stiffening,

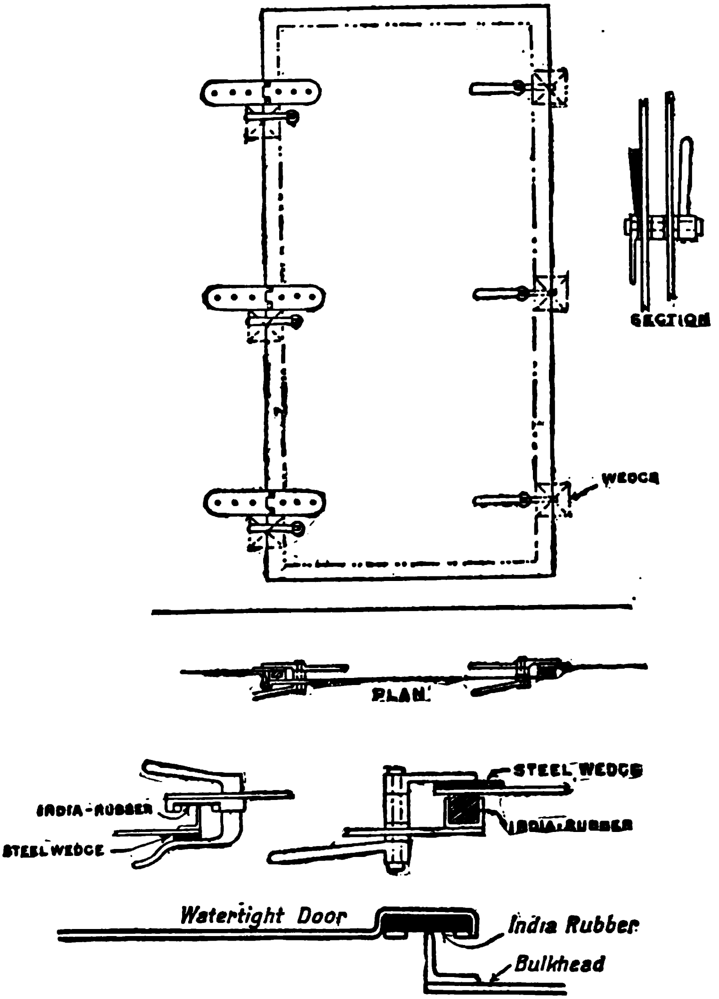

SECTION
WEDGE
PLAN.
INDIA-RUBBER
STEEL WEDGE
STEEL WEDGE
INDIA-RUBBER
Watertight Door
India Rubber
Bulkhead

FIG. 141.—Bulkhead Watertight Door.

Enlarged Sketches showing different methods of making Doors Watertight.

assisted by deep webs for vessels of great breadth in accordance with the conditions previously stated. Where this system of flanging is adopted, the plating should be increased in thickness $\frac{1}{20}$th for steel or $\frac{1}{16}$th for iron. In vessels with double bottoms, it is scarcely necessary to add, plate brackets will be required at the bottom of the flange stiffeners as for the ordinary system previously described. Fig. 138, G, shows the tank top brackets of the system of stiffening just described, or the brackets may be dispensed with by fitting a large angle continuous from margin plate to margin plate riveted to the face of the stiffeners and tank top as shown by the dotted lines. Fig. 138, J, shows still another system of flanging the bulkhead plating so as to form stiffeners chiefly for 'tween-deck bulkheads. Here, again, the plating should be $\frac{1}{20}$th or $\frac{1}{16}$th thicker.

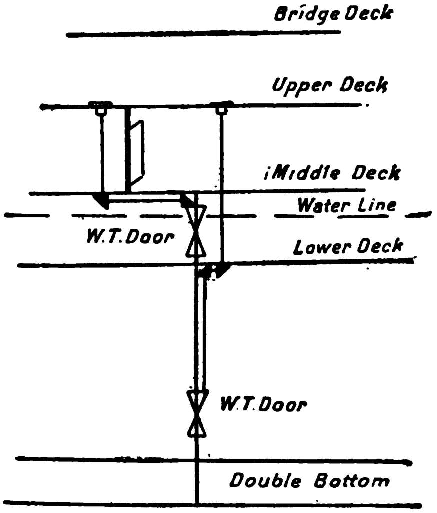


FIG. 142.—Watertight Doors manipulated by means of rods from Upper Deck.

Watertight Doors.

A golden rule to be kept in mind, in considering the bulkhead arrangement of a ship, is never to make a doorway, however good the system of securing watertightness may be, if it can possibly be avoided; for, as accidents from collision usually happen at unexpected moments, such doors are often open at these times, and many a good ship, from no other cause, has foundered. The aforementioned rule is rigidly observed by many of the companies owning large mail steamers. However, doorways through watertight bulkheads cannot always be avoided, especially in the 'tween decks when used for passenger accommodation.

Fig. 141 illustrates a watertight door, and several different modes of construction and fastening. Wherever watertight doors are required through a bulkhead below the load waterline, they should be either of the horizontal or vertical sliding type, and opened and closed by means of rods worked from the upper deck. (See fig. 142.)

Decks.

Steel Decks.—Under iron and steel decks it is always preferable to fit beams to every frame, and where the plating of such decks is thin, say, less than $\frac{7}{20}$ths in., it is imperative that this be done, because thin plating, when not supported by closely spaced beams, is liable to sag, or fall hollow in the spaces between the beams. Such beams may either be of plain angles, or bulb angles, increasing in size (particularly depth) for vessels of greater beam. (See figs. 12 and 46.) When, however, the deck plating is over $\frac{7}{20}$ths in. in thickness, the beams may be fitted to alternate frames, when the frame spacing does not exceed 24 in. or 26 in. Such beams must naturally be of extra strength, bulb plates with double angles, or tee bulbs usually being adopted. (See figs. 48 and 49.) Apart from the beams, the most important structural item in the deck is the stringer plate. This is usually of exceptional thickness, the reason for which will be readily understood when its function in assisting the shell plating, particularly the sheer strake, and in affording general longitudinal strength, is comprehended. Thus, in order to combine the deck stringers with the shell plating, it has become a common practice, especially in large vessels, to make the connection by means of double angles. This is necessary, principally in the upper or two upper decks, in large vessels with several decks. Where the frames terminate at the upper deck stringer plate (there being no erections), these angles connecting the stringer plate to the shell may be continuous. Where the frames extend through the upper deck stringer plate on account of an erection, and in the way of a lower deck stringer plate, these connecting angles must necessarily be intercostal. (See fig. 58.)

The butts of deck stringer plates should be at least double riveted, and, in large vessels, treble. The deck plating is arranged in strakes fore and aft across the beams. The edges are connected by a single riveted lap, and the butts for half length amidships should be double riveted, and single at the ends.* (Fig. 143.)

While steel decks are often fitted in preference to wood decks, they are often an indispensable structural part, required on account of the extreme proportions of the vessel. The longitudinal stresses, as we have seen at an earlier stage, being most severe over the midship length, it often happens that a steel deck may only be required for the half length amidships, in which case it should be gradually tapered off from the middle line towards the stringer plates. For the same reason, when the deck plating is $\frac{7}{10}$ths of an inch or more in thickness, at amidships, it may be slightly reduced in thickness towards the ends. Owing to the superiority of iron in resisting the attacks of the weather, and therefore suffering less from corrosion, such parts of deck plating as are exposed to the weather, are commonly made of iron, and elsewhere (where covered) of steel. In order to obtain equivalent strength, the iron plating should be somewhat thicker than the steel.

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* The overlaps of the butts of deck plating should look towards amidships. This prevents water lodging at the butt, and eventually injuring the caulking.

Of necessity, numerous openings are cut through the decks of all vessels,—engine and boiler openings, hatches, companions, etc. This naturally reduces the strength of the deck, and compensation in some degree must be provided by thicker deck plating, or doublings, in the way of such openings. As the deck is no stronger than its weakest section, a certain percentage of the maximum transverse strength should be maintained. Thus, over the midship half length, the aim should be to secure, especially in the strength deck (upper deck), 80 per cent. of the maximum sectional area of the plating.

Fig. 143 shows the upper deck plan of the vessel whose midship section and longitudinal profile are illustrated in figs. 12 and 46. The diagram shows that, as far as possible, butts of adjacent strakes have been kept at least two frame spaces clear of each other, and alternate strakes at least one frame space. The plating of the deck at the sides of hatches and engine and boiler openings has been increased in thickness; doublings have been fitted at the corners of the openings for all large hatchways and for engine and boiler casings, as, especially where such corners are rectangular, there is the tendency, owing to the severity of the racking stresses in such localities, to rupture. Doublings have also been fitted at the sides of small bunker hatches. When it is intended to sheathe a steel deck with wood, the strakes of deck plating should be arranged alternately, one in, one out. (See Wood Decks, fig. 58.) A slight reduction necessarily takes place in the thickness of the wood deck over all outside strakes of plating. The wood deck over the inside strakes should bear hard down upon the plating, and upon no account should the objectionable practice of fitting wooden packing pieces be permitted, in order to save thicker planking, or the trouble of efficient fitting. A sheathed steel or iron deck should be well coated with reliable bitumastic composition or vegetable tar, for it will easily be seen what havoc may be wrought in the deck plating in the event of water finding its way through defective caulking in any seam or butt in the deck planking, an occurrence not at all infrequent. When the deck plating is unsheathed, it is preferable to arrange the strakes of plating each in and out like the slates upon a roof as shown in the midship sections, figs. 12 and 48. By this arrangement, water on deck naturally flows towards the waterways, and finds its way through the scuppers. Every possible means should be taken throughout the vessel to prevent the lodgment of water, if the structure is to be preserved from corrosion and decay.

All steel decks should be thoroughly watertight, hence every seam and butt must be properly caulked. In the case of upper decks uncovered by erections, the watertightness against the shell plating is easily secured by the gunwale bar, which also ought to be caulked against the shell and the deck. In the way of the erections, and in 'tween decks, where the frames pass through the stringer plate, the watertightness is obtained by fitting a continuous angle bar along the toe of the transverse flange of the frame, to which it is connected either by an angle lug, or the extended reverse bar, and an intercostal angle between the frames against the shell; the space between these two angles is then filled with good cement.

Where the most satisfactory and reliable method of effecting water or oil-tightness is desired in a deck through which the frames extend, either joggled bars are fitted round all the frames, or else the frames are cut and a continuous angle attached to the shell and deck stringer plate, as shown in the 'tween decks of the midship section of the oil steamer, fig. 78. In this case the continuity of the strength of the frames is maintained by means of bracket plates to the decks. When the continuity of a steel deck is interrupted, as in the case of the raised quarter deck type, where the main deck extends for a certain length of the vessel, and is then raised several feet, after which it is known as the raised quarter deck, compensation for the break must be made. This is done by overlapping the decks (see fig. 47), excepting in very small vessels, when the main and raised quarter decks are bound together by large bracket plates well riveted to the bulkhead at the break.

Wood Decks.—When wood decks are laid upon the beams, they ought to be scored out on the under side in way of all tie and deck plates. No packing pieces should be allowed. The butts of the deck planking should be carefully arranged, there being at least three clear shifts between any two butts in the same beam space. Beams under wood decks are usually fitted on alternate frames, and are generally of bulb plate and double angles or tee bulbs. The butts of the deck planks should always come on the centre of the beam or on a deck plate. The butts are practically always of the vertical kind as shown in fig. 143, A.

The fantastic butts sometimes illustrated are seldom, if ever, adopted in mercantile shipbuilding practice. When the deck planks are 6 in. in width or under, a single through-bolt through every beam is sufficient. When the planks are above 6 in. and not more than 8 in. in width, there should be one through-bolt and a short screw-bolt on the under side in every beam. All planks over 8 in. in width should be fastened with two through-bolts through every beam. Through-bolts should be nut and screw. It is preferable that all bolts be galvanized. They should be properly sunk in the deck with their heads well bedded in oakum and white lead, and their heads should be carefully covered with turned dowels also bedded in white

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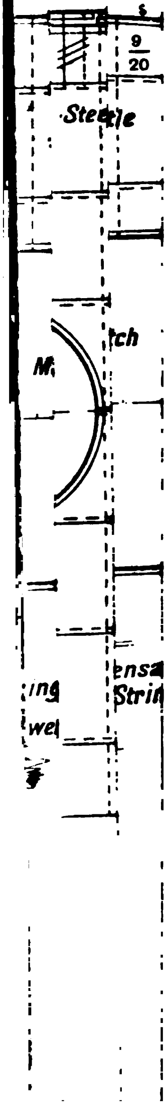

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lead or some suitable composition. (See fig. 143, A, for sketches of bolts, dowels, etc.)

The beams should be well painted with good red lead paint before the decks are laid; and in some cases, in order to preserve the appearance of the deck, by preventing discolouring due to rust water oozing through the butts, felt, dipped in red lead, is placed under the butts. In very high class work, zinc slips are fitted on the beams under the butts.

It is always better that the wood deck, alongside of iron deck houses, waterways, hatch coamings, etc., be of either teak or greenheart. All seams and butts should be caulked with oakum, and filled in with marine glue or some other suitable composition. When openings are cut through the deck for companions or skylights, care should be taken that the deck planks next to the openings are so secured as to prevent their yielding, due to the pressure caused by caulking. An excellent method of fitting an angle bar round such openings is illustrated in fig. 143, B. For the same reason, an angle bar should be fitted alongside all waterways.

All wood for decks should be free from sap, shakes, and knots, as far as possible. It should be well seasoned, and of good quality. Yellow pine, pitch pine, and teak, are among the principal timbers used, and not less than six months should be allowed for seasoning.

Teak decks, which are very durable, may be of less thickness than would be required for pine decks. In laying a deck, care should be taken that the weather side (the hard side) be uppermost, with the heart downwards.

When a wood deck is laid upon a steel deck, the butts and fastenings may come between the beams.

In order to get rid of the water which on weather decks naturally drains into the waterways, it is necessary that scuppers be fitted. Fig. 143, C, D, E, and F, shows four different kinds of scuppers.

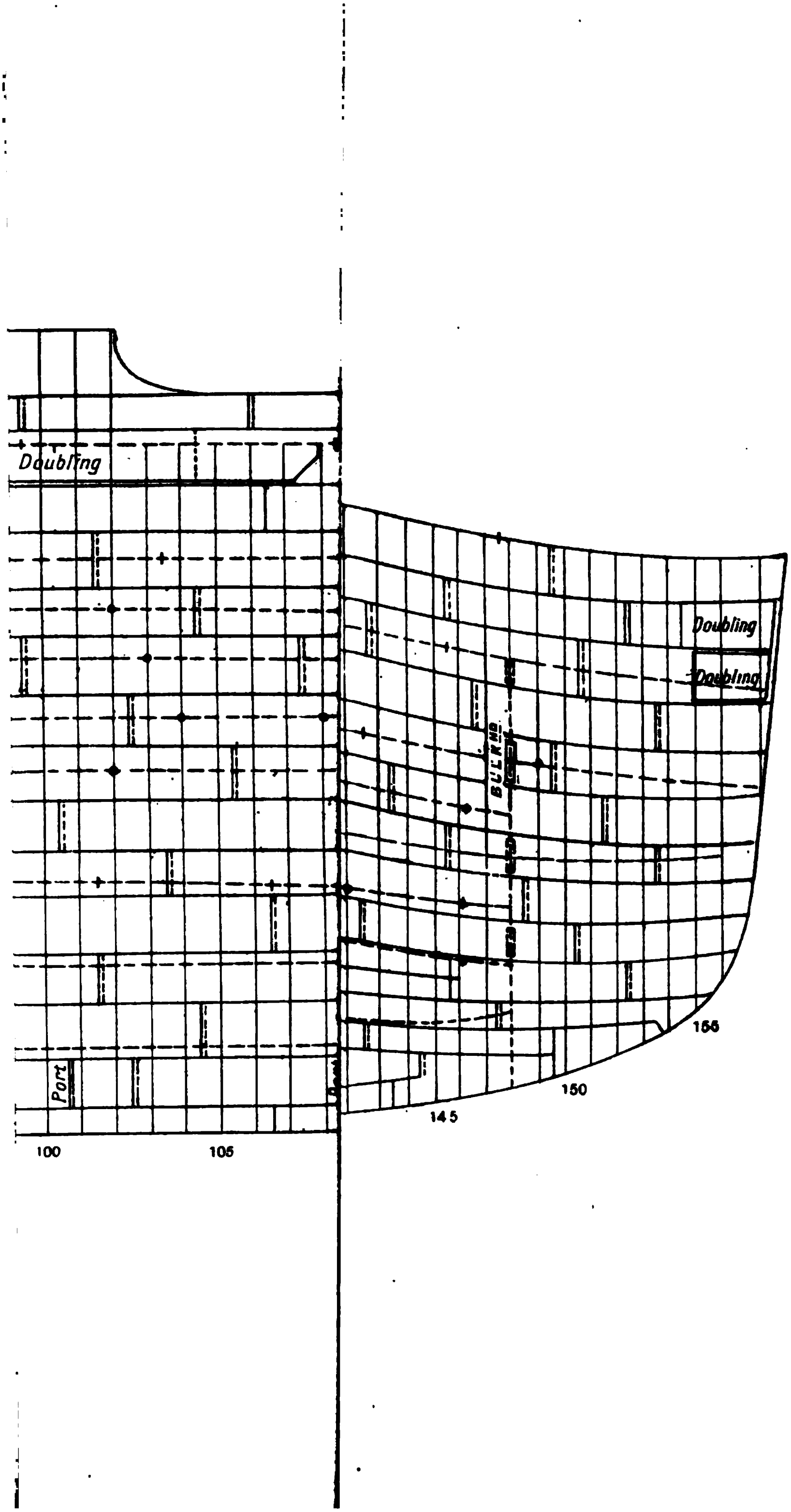
C shows a small aperture, 3 in. or 4 in. in length, cut through the sheer strake immediately above the deck stringer plate. The gunwale bar is preserved continuously as shown.

In F, owing to the gunwale bar being cut at the scupper, a compensation bar is fitted on the under side of the stringer plate.

D and E are forms of scuppers adopted in bridges, or poops, or 'tween decks, water finding its way through these by a perforated brass plate fitted into the stringer plate, while storm valves are usually fitted to the shell exit to prevent water finding its way into the ship through the scuppers; or, in some cases, screwed lids are fitted on to the perforated deck plate for the same purpose.

Outside Shell Plating.

While the skin or covering over the framing of all vessels is an indispensable part of the structure, in iron or steel vessels the outside shell plating, while performing the work of a watertight skin, is also the principal structural item in the ship girder. A steel ship being composed of a vast number of minor girders, each contributing its share to the strength of the whole, it follows that to consider alone the isolated efficiency of any particular part is unfair. Thus, while the shell plating affords enormous longitudinal strength to the vessel, it depends upon the assistance of the transverse framing, as well as upon the keelsons, stringers, and decks, in being held to its work, and developing its fullest efficiency. Some parts of the outside plating develop more strength than others. This we investigated in Chapter V. on 'Stress and Strength.' Thus, it is usual to find in all seagoing vessels that the plating is of increased thickness on the topsides, particularly in the sheer strake, and possibly in the strake beneath. In some cases, especially in large long vessels, the sheer strake may even be doubled. As the sheer strake is usually and preferably an outside strake, such a doubling would generally be placed on the inside of the sheer strake. Increased thickness of shell plating is often found to be necessary in one or more strakes of the bilge plating, which is the lower extremity of the ship girder, just as the sheer strake forms the upper. As the longitudinal stresses are greatest over the middle length of the vessel, and are gradually reduced towards the ends, a reduction in structural strength is permissible. We therefore find that all classification societies allow for this in their rules. The midship thickness is usually continued over the half length amidships, reduction gradually taking place towards the ends. However, when we come to the keel and stern frame, the local requirements demand that thick plating be adopted. In the case of the keel, this is easily understood when it is remembered that there is the possibility of the vessel frequently lying aground, with consequently severe wear and tear. The necessity for thick plating, where flat plate keels are adopted, is obvious. When a keel of the bar type is fitted, the strakes of shell plating which are attached to it on either side (the garboard strakes) again require to be of exceptional thickness. This is necessary in order to obtain plating somewhat compatible with the thickness of the bar keel and its large, widely-spaced rivets. The absurdity of riveting a thin plate to a thick bar with large rivets widely spaced, is evident if watertightness is to be ensured. As previously pointed out, the lower edge of the garboard strake should be kept about a quarter of an inch from the bottom of the keel, not only to facilitate caulking, and relieve the plating of strain in the event of grounding, but to preserve the caulking and watertightness which would suffer, should such vessels be accustomed to chafe on sandy bars of bottoms. The shell plating which is connected to the stern frame should be at least of the midship thickness for reasons just given, where plates have to be connected to thick bars or forgings. Moreover, the vibration which is suffered in this locality, owing to the action of the propeller, when being immersed and emerged in heavy seas, demands that the parts of the material connected have some relation towards each other. Thick plates


Doubling
Doubling
Doubling
BULKHD
Port
100
105
145
150
155

are particularly required round the boss. As both boss and oxter plates (shell plating over propeller arch) have to be furnaced and hammered in order to be brought to their required shape, these plates must be annealed before being fixed in position. By increasing the thickness of the shell plating at the fore end for about 20 or 30 ft. from the stem, ships which have frequently to break their way through ice may be considerably strengthened. Such thickening of shell plating will also enable the vessel to more effectively resist panting action, and minimise the tendency in lightly-built vessels to fall hollow between the frames, owing to the pressure upon the bows when driving ahead. This also makes a more satisfactory connection to the stem bar. Where this increased thickness is adopted only on account of the possibility of ice being encountered, such increase of thickness need only extend between light and load lines. One or two shell strakes on either side of the keel should of necessity preserve their midship thickness to the stem, on account of the severity of the thumping which ships experience when driving ahead and plunging into head seas.

A most important consideration in the arranging of shell plating should be to ensure a good disposition of butts. No butts in adjacent strakes should come nearer to each other than two frame spaces, and in alternate strakes than one frame space. Similarly, butts of deck stringers, side stringers, tank margin plates, centre through-plates, keelsons of bar keels, or butts of side bar keels, should be kept clear.

Fig. 144 illustrates an expansion of the shell of one side of a vessel, and shows the disposition of butts, etc.

Where very short plates are adopted in the outside shell, to carry out such an arrangement would be impossible, hence it is usual to stipulate that no shell plates be less than 7 frame spaces in length, excepting the plates at the extreme ends of ships. Indeed, with the adoption of larger and improved machinery in recent years, shell plates of 10 and more frame spaces in length are commonly adopted. The nature of butts and seam connections, including the riveting, has been fully dealt with and illustrated in Chapter VII., p. 167.

Packing.—When the strakes of shell plating are arranged alternately, one inside (*i.e.* bearing upon the frames) and one outside (*i.e.* the edges resting upon the edges of the adjacent strakes and forming the seams), as illustrated in figs. 12, 48, etc., it will be seen that something must be done to secure a firm connection between the outside strakes and the frames. This is effected by fitting what is called 'packing iron' on all frames in way of all outside strakes of plating. This packing iron must necessarily be of the thickness of the adjacent inside strakes. The riveting through all outside strakes and the frames must therefore pass through this packing iron. Packing iron is necessary, not only in the shell plating, but in decks, tank top, etc., when this arrangement of plating is adopted. When a steel deck is laid with the strakes of plating in and out, as shown in the three steel decks of fig. 48, and also on the tank top of the same fig., the packing iron must of necessity be tapered to suit the shape of the space between the beam or reverse bar and the plate, as the case may be. Sometimes an in and out strake is adopted in the shell plating (see the bilge strake in fig. 48), when taper packing is likewise necessary. All this packing obviously adds greatly to the weight of a vessel; but in recent years it has been largely dispensed with by joggling the edges of what would be the outside strakes of shell plating, decks, tank tops, etc. (See figs. 64, 65, and 78.)

By this means, not only is a saving of weight effected, but superior workmanship is assured, for a standing rule ought to be, never to rivet through more than two thicknesses if it can possibly be avoided,—the less the number of thicknesses, the more reliable the riveting.

The strength of butt joints, and the size and spacing of rivets in both seams and butts, has already been dealt with in Chapter VII., p. 167. In order to obtain watertightness, and to thoroughly close up the shell plating, the following two points should be noted:—

Where the seam over-lap of an outside strake passes over a butt lap in the adjacent strake (see section through plate landing *x y*, fig. 145) the plating of the butt under the landing is planed off in a tapered form, as shown in the diagram, so as to allow the outside strake to bear close on the inside strake, without leaving a tapered aperture, which would otherwise exist were this planing operation not adopted. In the event of this not being done, a piece of tapered packing iron would have to be fitted. In lapped butts of outside strakes, it is not practicable to so plane the butt, and thus tapered packing pieces long enough to take at least three pairs of rivets are fitted.

Wherever the shell plating is weakened owing to excessive perforation by rivet holes, or by the cutting of doors or openings of any kind, compensation should be introduced. Thus, in way of all watertight bulkheads, the shell is perforated by a row of closely spaced rivet holes. This weakness is compensated for by the fitting of bulkhead liners in way of the outside strakes. (See figs. 139, 140, 144, 83, and 84.) Bulkhead liners have already been more fully dealt with in the section on 'Bulkheads,' as well as in the section on 'Oil Steamers.' When side lights are cut through a sheer strake, compensation for the weakening of the strake should be introduced, either by increasing the thickness of the plating, or doubling the same, or fitting stout angle bars for at least one frame space in length over all such openings. When openings for doors of any kind are cut through the shell plating, compensation must be made by fitting doubling plates above and below such openings by framing the opening with stout angle bars, and by fitting vertical webs upon each side of the opening, and a fore and aft girder upon the shell above these openings extending a few feet fore and aft on each side of the doorway. Such of these methods should be adopted as are in accordance with the special requirements of the case. In very large vessels and in vessels of extreme length in proportion to the depth, to fit doublings to the sheer strake, and in some cases, even to the strake

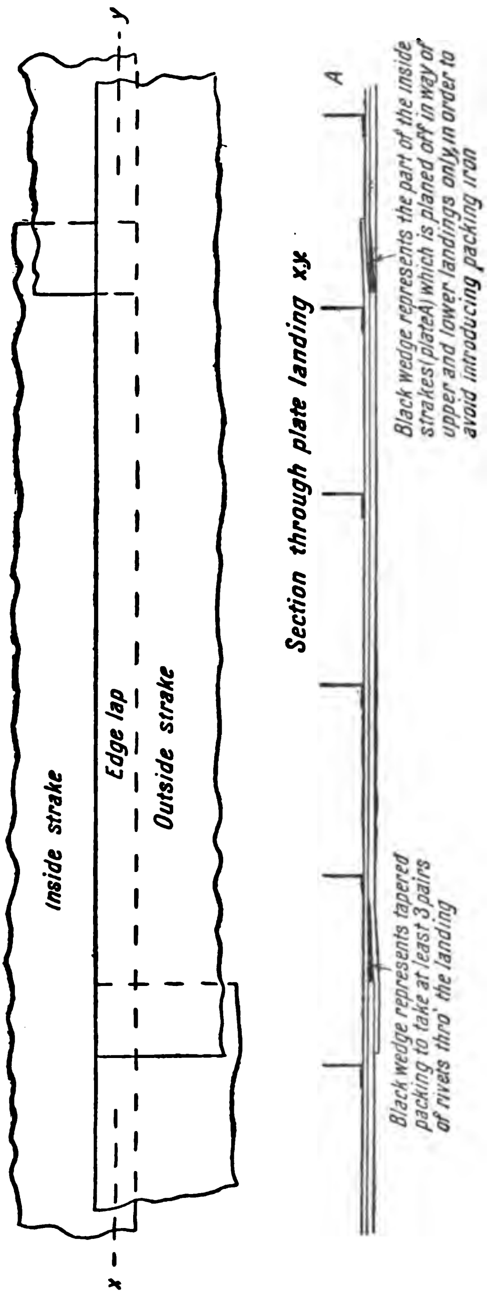

y
Inside strake
Edge lap
Outside strake
x
Section through plate landing xy
A
Black wedge represents the part of the inside strakes (plateA) which is planed off in way of upper and lower landings only, in order to avoid introducing packing iron
Black wedge represents tapered packing to take at least 3 pairs of rivets thro' the landing

FIG. 145.—Showing the mode of obtaining close work (watertightness) at the butts of both outside and inside strakes of shell plating.

below is sometimes necessary. When this is done, the butts are usually connected by means of straps, these being necessary for the doublings as well as the other plating.

At the ends of bridges and raised quarter decks or any other erections terminating on the half length amidships, doublings should be fitted to the sheer strake, or, in the case of raised quarter decks connected to bridge houses, the raised quarter deck side plating above the sheer strake should be doubled, the doubling to extend from four or more spaces along the bridge side to a considerable distance abaft of the break according to the size of the vessel. Doubling plates should be fitted round hawsepipes. (See Doublings, fig. 144.)

The bulwark plating at the ends of long poops and forecastles, and at both ends of bridges, should be increased in thickness, so as to somewhat reduce the sudden interruption in longitudinal strength, which such erections create. All openings through the bulwarks for waterport doors, or mooring ropes, should have narrow doubling plates fitted round them. As the bulwark is usually constructed of thin plating about ¼ in. in thickness, it obviously requires stiffening upon its upper edge. This may be done by fitting special sections of bar iron, which are rolled for this purpose, or bulb angles with half round iron on the outer edge, or even in some of the cheap tramp types of vessels, a couple of half rounds, one on either side of the top edge of the bulwark plating, may be fitted. (See figs. 10, 11, 12, 48.)

The bulwark plating also requires supports of some kind from the deck. These may be specially forged round iron stanchions with a palm on the top and a fork at half the height, also with a palm to take the bulwarks, the lower end of the stanchion being riveted to the deck. Other forms of bulwark supports are also made of tee bars and bulb plates. See figs. last referred to.

These bulwark stays should not be spaced more than about 6 ft. apart.

When the butts in the sheer strake are strapped it is preferable to fit the straps on the outside, covering the full width of the plate. But as this is not only unsightly, and often inconvenient, the straps are fitted on the inside, when they should extend from the edge of the strake below to the extreme top of the sheer strake, in which case the gunwale angle bar should be joggled round the straps. When double straps are required to the sheer strake, the outer one must extend over the full width of the plate, while the inside one may extend from the edge of the strake below to the deck stringer plate, and be fitted in a separate piece from the bosom of the gunwale bar to the top of the sheer strake. In this case, a packing piece must be fitted above the top flange of the gunwale bar.

The sheer strake ought to extend sufficiently high so as to get two rows of rivets through the straps above the gunwale bar.

All butts should be carefully planed and fitted close. All butts and seams must be thoroughly caulked.

In preparing a shell plate for its position in the ship, the position of all frame rivet holes (which are punched before the frames are erected) and rivet holes in the seams of adjacent plates, are transferred to the new plate, by means of a template. A template is a framework made of thin wood large enough to cover the area of the plate, with wooden bars across in way of each frame. This is pinned on to the vessel in exactly the same position which the plate itself will occupy, and by means of a whitened cylinder the positions of the rivet holes are transferred to the template. The template is then taken down and laid upon the plate, and by means of what is called a reversing tool the rivet holes are re-transferred to the plate, which is then carried away to be punched, countersunk, and sheared to its exact size. It is then lifted into position in the ship by means of block and tackle, and securely bolted in place. Indeed, the plate must be held by a sufficient number of bolts so as to bring it absolutely close to all surfaces upon which it must fay. In riveting such a plate, especially where the length is great, the riveting is performed from the centre toward the outer edges. By this means, if any slight expansion occurs, due to hammering, and heat from the rivets, it is evenly distributed in all directions, and is therefore practically unnoticeable.

In those parts of the shell where there is considerable change of form, the exact curvature of the plate is ascertained by strips of bar iron (set-irons) bent to the correct shape at two or more positions in the length of the plate. The greater number of shell plates can be bent to their required shape in the 'rolls,' manipulated by skilful platers.

Plates of more irregular shape need to be furnaced and hammered into the required form, and should be annealed.

Stern Frames and Rudders.

Stern Frames.—The function of the stern frame in a single screw steamer is to afford support to the rudder and to the tail end shaft and propeller, and to provide an aperture in which the propeller may revolve. The usual form of stern frame for vessels with single screws is shown in fig. 146. Its principal parts are an after or rudder post into the gudgeons of which the rudder pintles are fitted, and a fore or propeller post through the boss of which the tail end shaft passes to carry the propeller. It is obvious, therefore, that with the enormous stress which must be borne by the stern frame, especially in large high-speed vessels, that it must be exceptionally strong in itself, and at the same time that the connection to the main hull of the vessel must be of the most efficient character.

Stern frames may be of cast steel or forgings made by first forging parts of the stern frame in separate pieces, and then welding the whole together. Naturally, great care must be exercised in the manufacture of a stern frame. The material should be as free as possible from any excess of those elements which are known to produce brittleness. If castings are adopted, they should be free from blow-holes and cavities of any kind, and in the case of

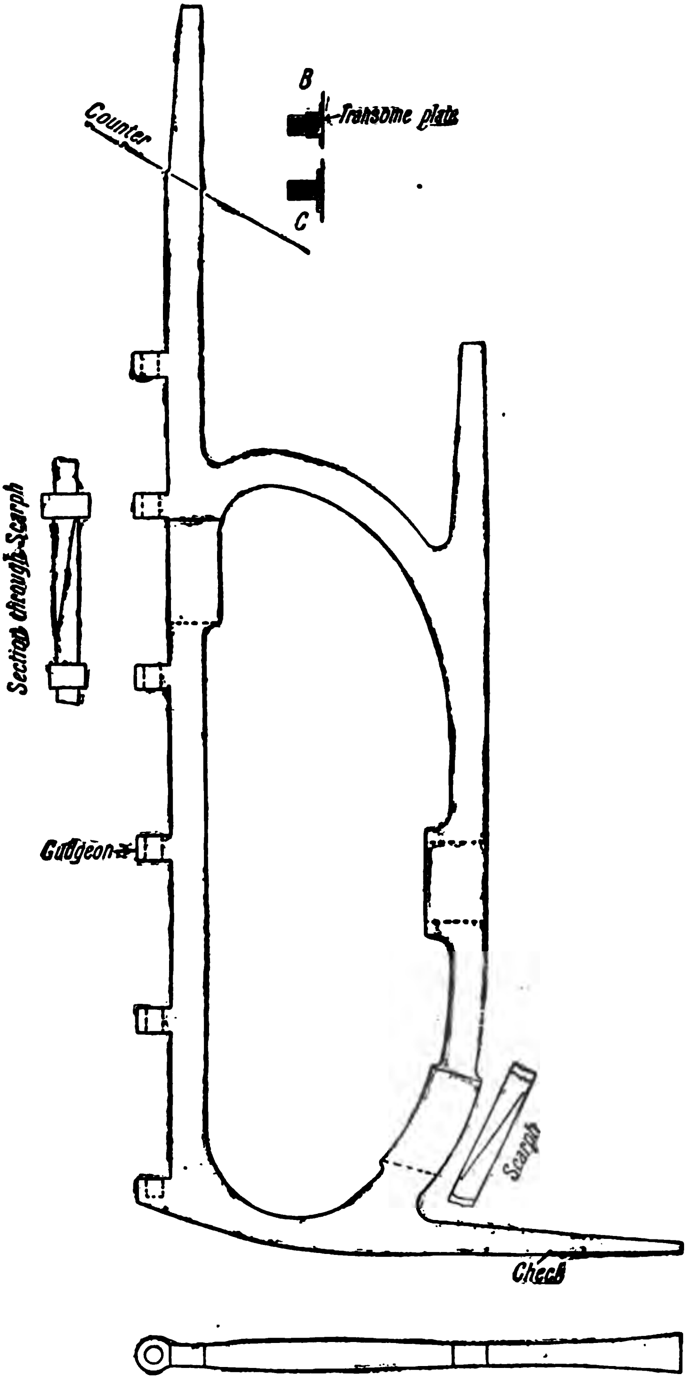

B
Transome plate
Counter
C
Section through Scarph
Gudgeon
Scarph
Check

FIG. 146.—Stern Frame for a Single-Screw Steamer. Frame in two parts connected by Scarphs.

forgings, the utmost care is necessary in making the welds uniting the several parts. The tests for stern frames have already been given on page 24. The classification societies definitely specify the dimensions of a section through any part of the stern frame, based, as a rule, upon the 2nd numeral. A safe rule to follow is to preserve the standard sectional area, if the vessel is classed, through every section in the circumference of the frame. When a vessel trims by the stern, it follows that if she comes into shallow water, the aftermost extremity of the keel, which would be formed by the base of the stern frame, would be the first to touch the bottom. This has frequently happened, with the result that the stern frame has been broken usually at the bottom of the aperture. Sometimes, by fitting a shoe strap, the stern frame may be sufficiently repaired so as to continue to serve its purpose. In other cases, where the damage has been more extensive, the whole stern frame has had to be renewed.

When the whole stern frame is made of a casting or forging in one piece, the enormous difficulty, and labour, and expense, not to mention loss of time incurred in extricating the broken stern frames from the hull, and in ordering and refitting a new stern frame, will be apparent. To obviate this, the arrangement shown in fig. 146 whereby the stern frame is made in two or more pieces connected by means of scarphs as illustrated is now commonly adopted, especially in large vessels, and as the damage from grounding usually takes place either at the bottom of the aperture, or in the after post, it will be seen that this piece can be renewed with comparative ease. A commendable method which may often save a stern frame in the event of grounding, is to lift up the frame at the bottom of the aperture from the propeller post to its aftermost extremity, as shown in figs. 146 and 157. As this may, in some cases, bring the lower part of the stern frame round the bottom of the aperture, in too close proximity to the propeller, the frame is reduced in depth, but increased in breadth at the bottom of the aperture, preserving the sectional area, as illustrated by the plan of the stern frame, fig. 146.

The connection of the stern frame to the hull, which, as previously stated, should be of the most thorough character, is effected—

1st. By carrying up the after, or rudder post, to a height sufficient to enable a good connection to be made to a thick plate called a transome floor, which extends from side to side of the vessel above the counter on the fore side of the post. (See fig. 146, B and C.) Lloyd's require that the depth of this transome plate be at least one and a half times the depth of an ordinary midship floor.

2nd. In large vessels, and in all single screw vessels of high speed, the fore or propeller post should extend to a height sufficient to enable a good connection to be made to another deep transome or floor plate. Lloyd's require the propeller post to be extended as just described in all screw steamers whose plating number is 20,000 and above.

The rudder and propeller posts are connected to their respective transome plates, either by means of large stout angles (see fig. 146, B), or by having a projecting flange upon the post itself, through which the rivet holes are drilled for the connection to the transome plate. (See C.)

3rd. The lower part of the stern frame which projects forward of the propeller post, should be of sufficient length to enable a good connection to be made to the keel. In screw steamers, shipbuilders usually make this projection at least three frame spaces. Lloyd's require that the projection be at least 2½ frame spaces before the propeller post in steamers, and 1½ in sailing vessels and paddle steamers. When the keel is of the bar type, the stern frame is connected to the keel by a scarph, as shown in fig. 99, which is in every way similar to the scarphs uniting the several lengths of the bar keel. When the keel is of the side bar type, the scarph is formed as shown in fig. 100. When the keel is of the flat plate type, the projection forward of the propeller post is usually formed as shown in fig. 146. It will be seen that it tapers in respect to its depth, and forward of the check on the bottom of the projection, where the keel plate terminates, it is hollowed out, and conforms to the shape of the bottom of the vessel. The keel plate is thus riveted to the stern frame by independent rivets for each side.

4th. The stern frame is finally attached to the hull by means of the shell plating, which is riveted to it by at least two rows of rivets arranged in zigzag fashion. These rivets should be spaced not more than five diameters apart, and should be about a quarter of an inch larger in diameter than would be required according to the thickness of the plates, which ought to be, at least, as thick as the garboard strakes. Lloyd's, however, state that they need not exceed 1¼ in. in diameter, as it is practically impossible to get efficient hand riveting with larger rivets.

Although the shell plating is reduced in thickness from the half-middle length to the ends, the plates which take the stern frame should be at least equal to the midship thickness or garboard strake thickness, and especially so round the boss of the propeller post, for the absurdity of connecting a huge, heavy stern frame, weighing twenty or more tons, to comparatively thin plating by large rivets must be apparent.

The rudder is supported and secured to the propeller post of the stern frame, though with every facility to swing freely, by means of pintles, which fit into a number of gudgeons on the rudder post of the stern frame. Detailed sketches of these gudgeons are shown in figs. 147–151. The spacing of these gudgeons upon the stern post should not exceed 5 ft. 6 in. Whether the stern frame is of cast steel or forged iron, the gudgeons should form an integral part of the post. The weight of the rudder is usually borne upon the bottom gudgeon, though, in some cases, the weight is taken upon one of the decks, through which the rudder stock passes, by means of a collar forged on to the post which rests upon a suitable casting firmly secured to the deck and well supported. However, the after stern post is not so absolutely necessary as has sometimes been supposed. In the profile of the turret steamer (fig. 63) built by Messrs. Doxford & Sons, the after post is dispensed with in way of the screw aperture, the fore post being projected aft in order to afford support to the lower extremity of the rudder, the weight of the rudder in this case being carried at the deck. An advance has even been made beyond this, and Messrs. Alfred Holt & Co., of Liverpool, have shown in their latest single-screw steamers that the huge, heavy, costly, and cumbersome stern frame can be dispensed with altogether by the ingenious and well-thought-out arrangement illustrated in fig. 75.

This system of stern arrangement has already been dealt with on p. 150. Notwithstanding the radical change which has taken place in this stern arrangement, and the suspicion with which such innovations are often viewed, several of these vessels have performed with complete success the round journey to China and back, carrying a deadweight of over 8000 tons, while the increased facility for steering has proved a decided advantage. Cutting away and dispensing with the fin of plating extending from below the boss to some distance forward, has not only lessened the resistance to steering, but reduced the severity of the straining and vibration which is usually experienced in this neighbourhood.

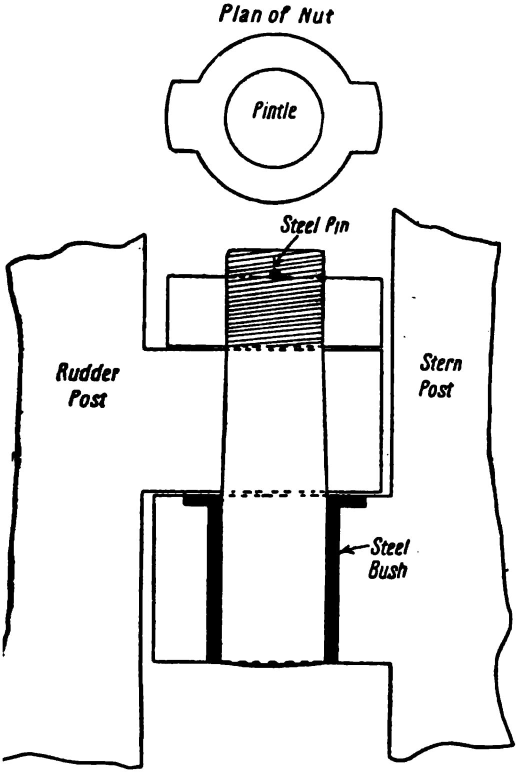


FIG. 147.—Fitted Pintle.

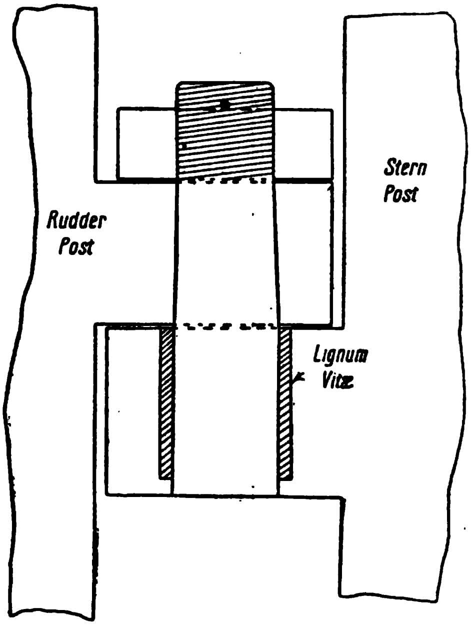


FIG. 148.—Fitted Pintle.

The rudder, which is of special design (see fig. 75), is of such a shape as to offer the least resistance to propulsion compatible with the principle of its design.

Stern Arrangement for Twin Screws.—In all vessels with twin screws, there comes a place towards the stern where the propeller shafts would emerge from the hull, if the usual form of hull were in no way modified. The length, from the point where the shafts so emerge to the propellers, will vary according to the size and fineness of the lines of the vessels, therefore

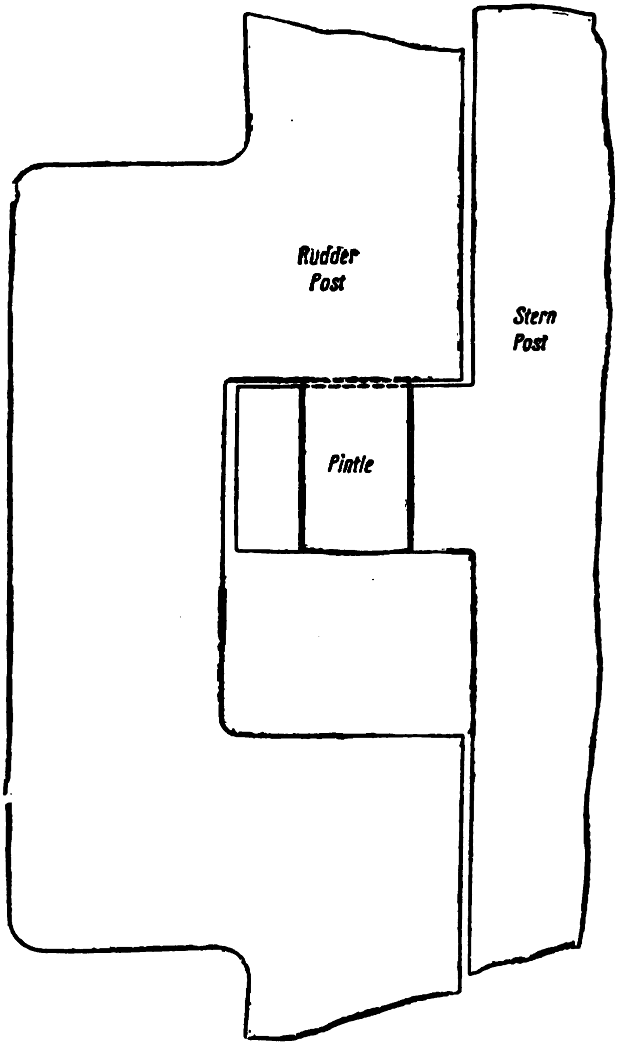


Fig. 149.—Pintlets forged on Rudder Post (unbushed).

in all such cases the shafts require support at their aftermost lengths. The old-fashioned method of affording this support was by bossing out a few frames round the shaft in the neighbourhood where it would emerge through the shell plating, and at the aftermost extremity supporting the

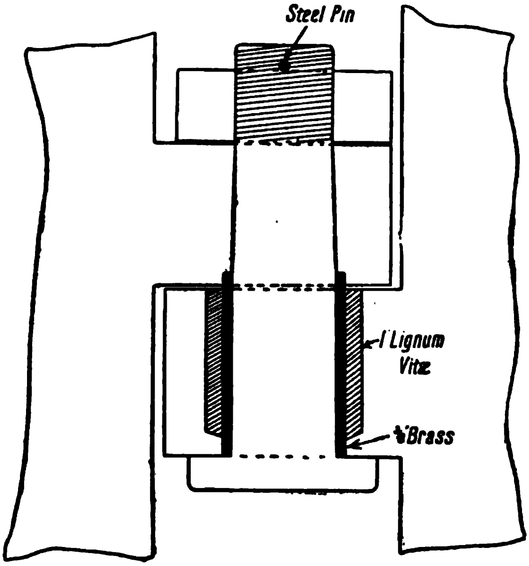

Steel Pin
1" Lignum Vitæ
½" Brass

Fig. 150.—Locking Pintle.

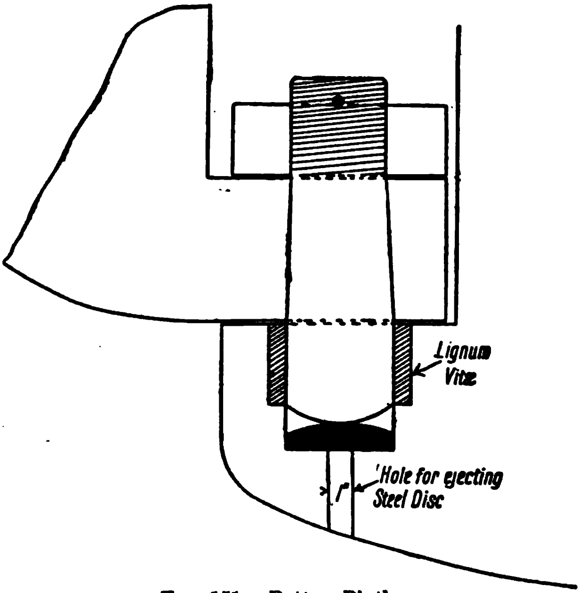

Lignum Vitæ
Hole for ejecting Steel Disc

Fig. 151.—Bottom Pintle.

shafts by means of struts such as shown in figs. 153, 154, 155, and 156. These struts may be either forgings or castings.

In fig. 153 there is a stern frame somewhat after the pattern required for a single screw. The aperture in this case is necessary, because the propellers overlap to some extent, and, as the diagram shows, the stern frame is manipulated to receive the palms at the upper and lower extremities of the struts.

In fig. 154 the propellers are amply clear, and no aperture is necessary. In this case, the upper palms of the struts are riveted on to the shell plating, which is doubled, and supported by a thick bulkhead with large, thick, double angles through which the rivets of the upper palms pass. (See fig. 155.) The lower palms are riveted through the keel bar, or through the keel part of the stern post. In fig. 156 the struts pass through the shell plating, and the upper palms are secured to a fore and aft, and to a transverse plate, as shown; but by far the best method of supporting twin-screw shafts at their aftermost extremities is to carry the framing round the shaft right aft to the propellers, and to work the shell plating round this. With a sufficient number of transverse ties and bulkheads, this arrangement is exceedingly strong, and much less liable to suffer damage than the strut arrangements previously described.

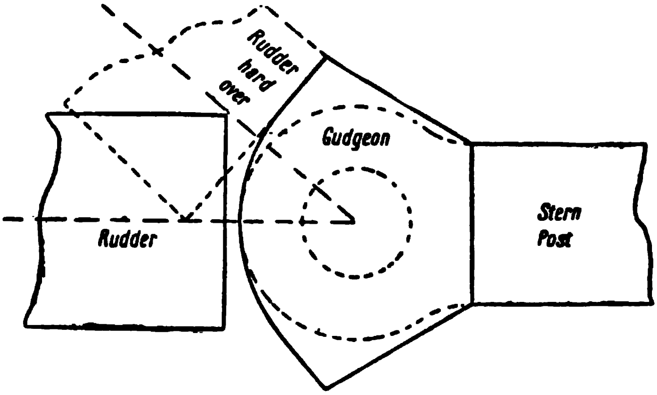
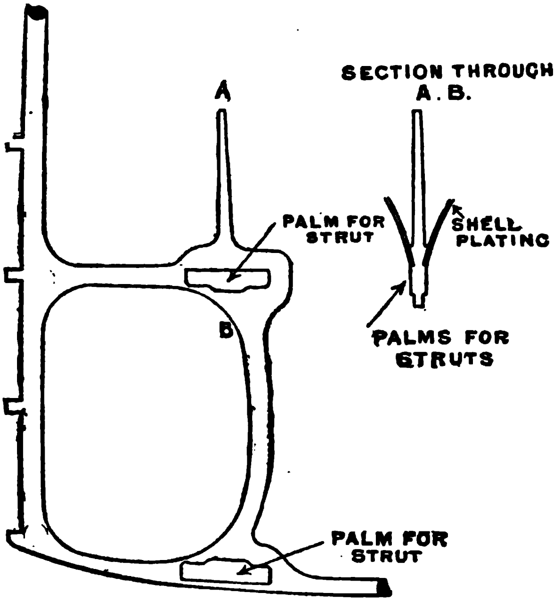


FIG. 152.—Rudder Stopper.

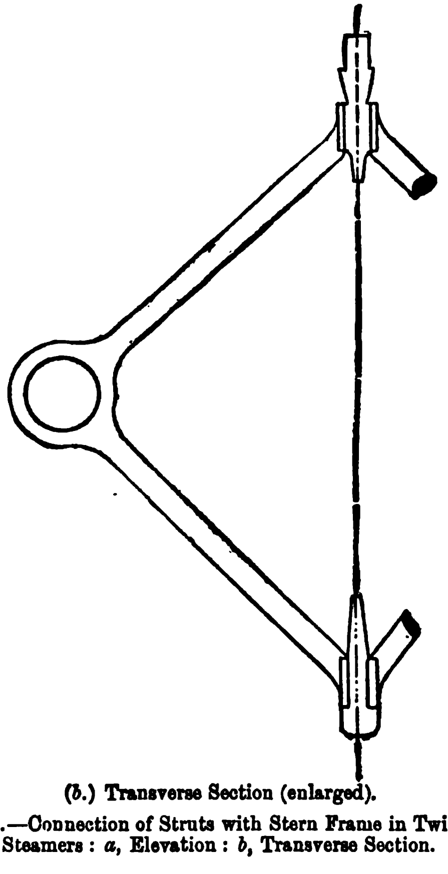
Special support is provided for the extreme ends of the tail shaft by means of what are commonly known as the spectacles. This is usually a steel casting, in one piece, firmly bolted through the fore post of the stern frame, and securely riveted to the bossed plating of the shell. The notes upon the diagrams are sufficient to give a general idea of this mode of construction (figs. 157 and 158).

Rudders.

Rudders for merchant steamers may be divided into two kinds, the ordinary frame rudder and the plate rudder. The frame rudder is usually


A
SECTION THROUGH
A.B.
PALM FOR
STRUT
SHELL
PLATING
B
PALMS FOR
STRUTS
PALM FOR
STRUT

(*a*.) Elevation.



(*b*.) Transverse Section (enlarged).

FIG. 153.—Connection of Struts with Stern Frame in Twin-Screw Steamers : *a*, Elevation : *b*, Transverse Section.

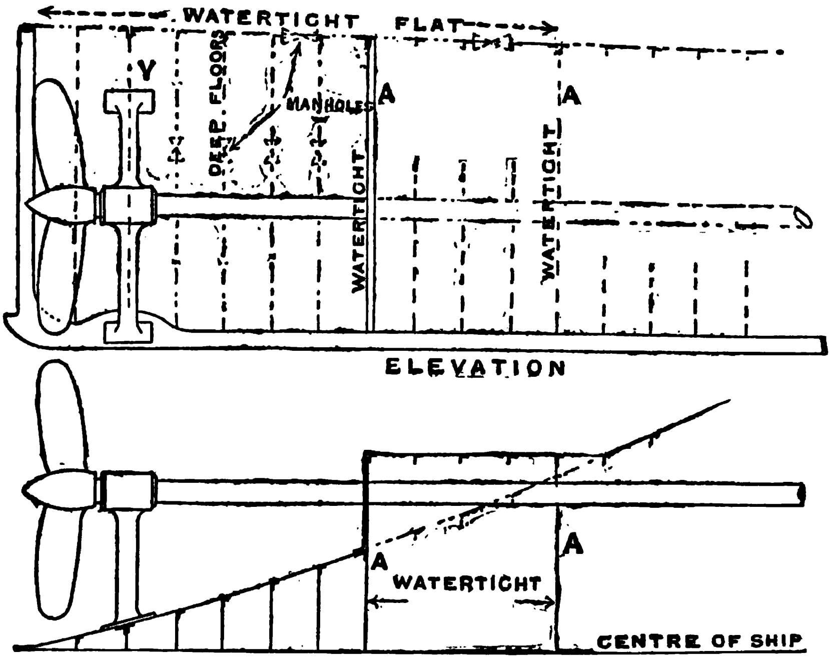

WATERTIGHT FLAT
Y
DEEP FLOORS
MANHOLES
A
A
WATERTIGHT
WATERTIGHT
ELEVATION
A
A
WATERTIGHT
CENTRE OF SHIP

FIG. 154.—Mode of Strengthening Ship at the after end and attaching Struts to Shell Plating.

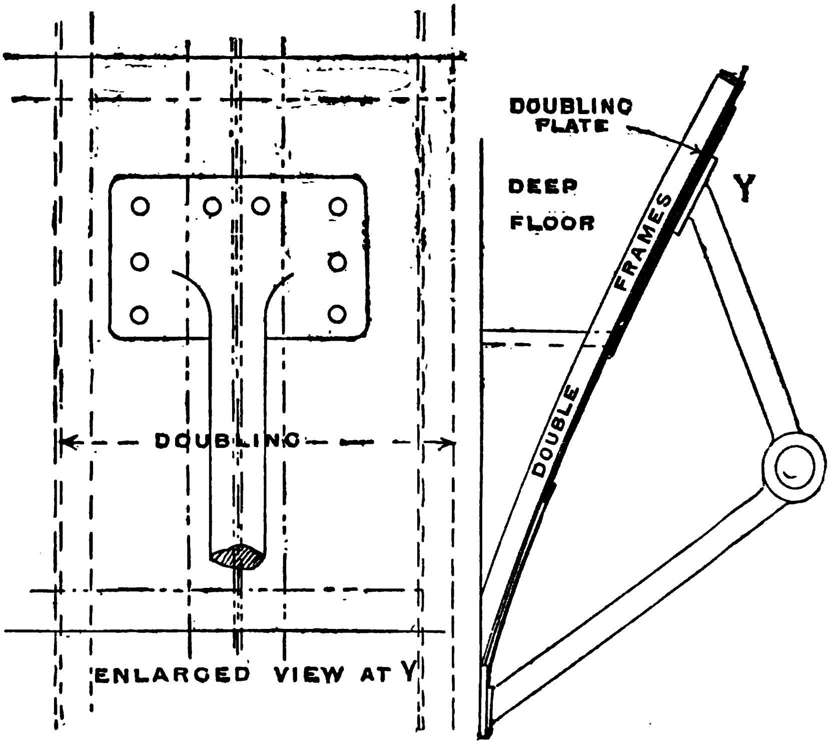
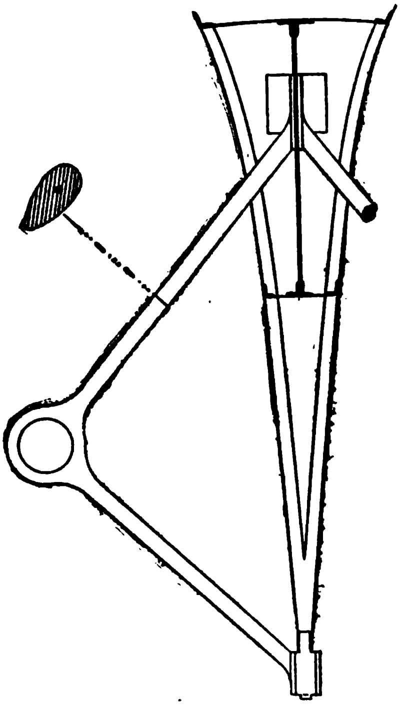
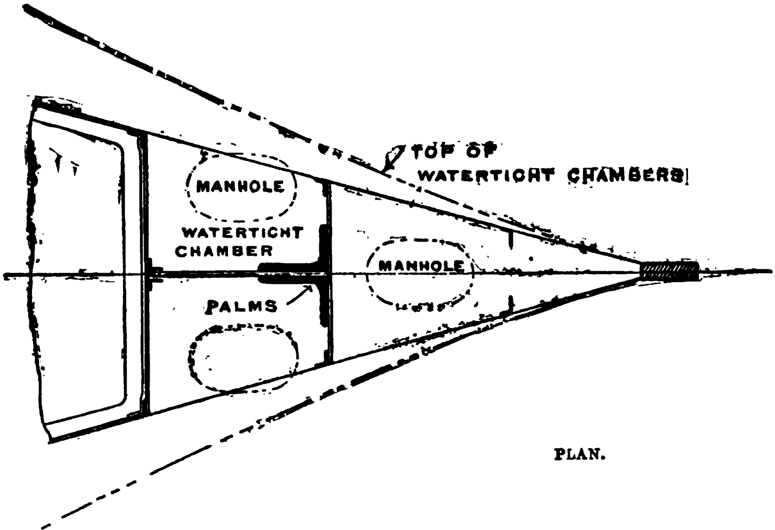

DOUBLING PLATE
DEEP
FLOOR
Y
DOUBLE FRAMES
DOUBLING
ENLARGED VIEW AT Y

FIG. 155.—Mode of Strengthening Ship at the after end and attaching Struts to Shell Plating.



Sectional Elevation of Struts.


TOP OF
WATERTIGHT CHAMBERS
MANHOLE
WATERTIGHT
CHAMBER
PALMS
MANHOLE

PLAN.

Fig. 156.—Struts carried through Shell Plating into Watertight Chamber.

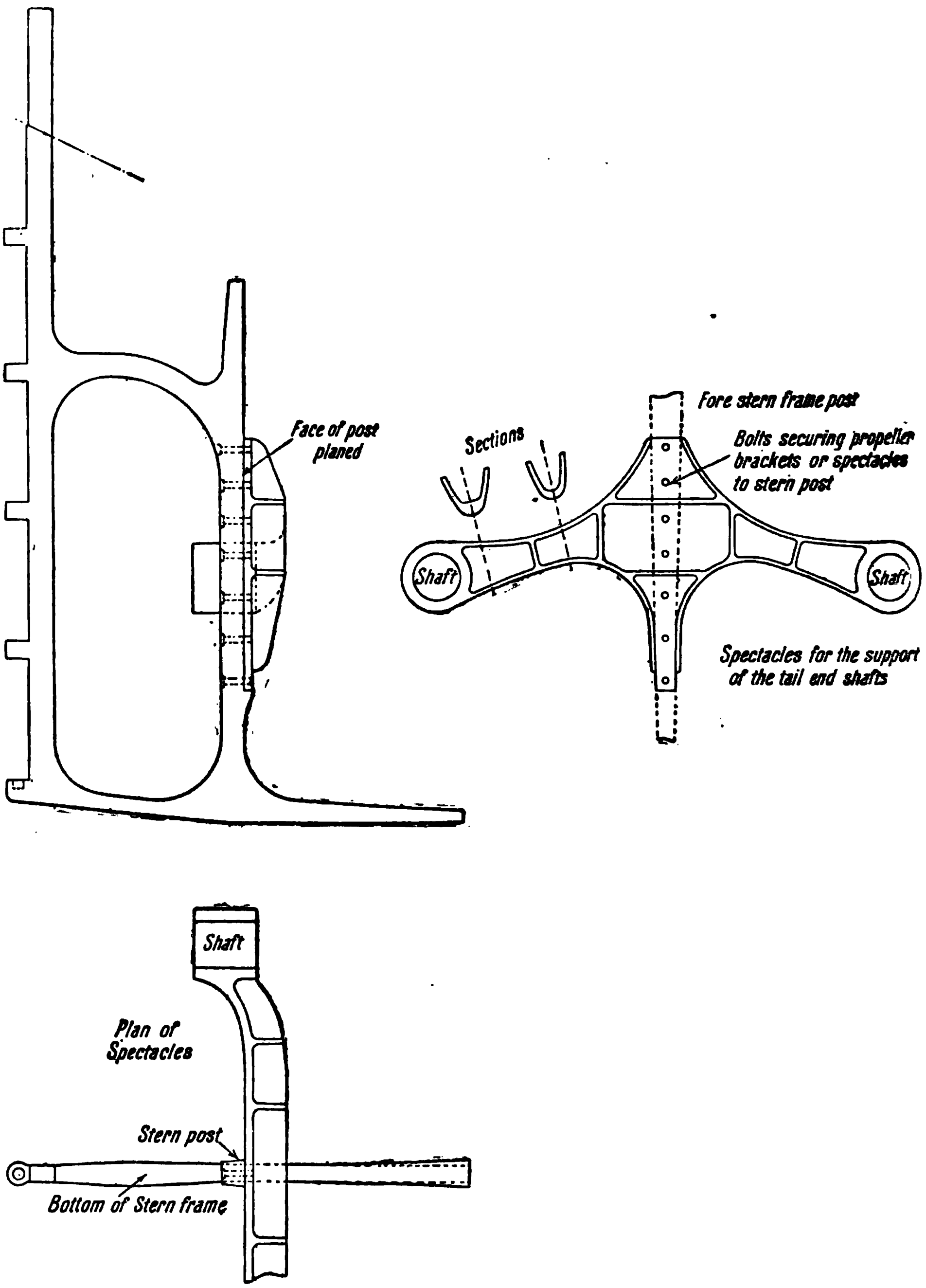
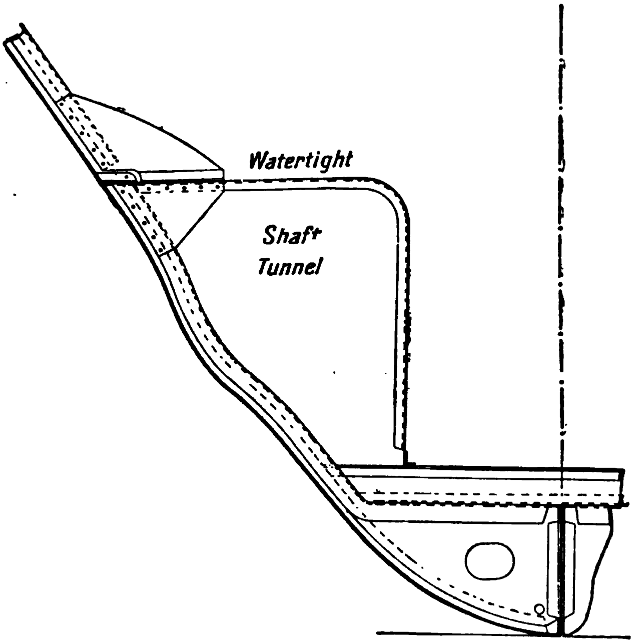
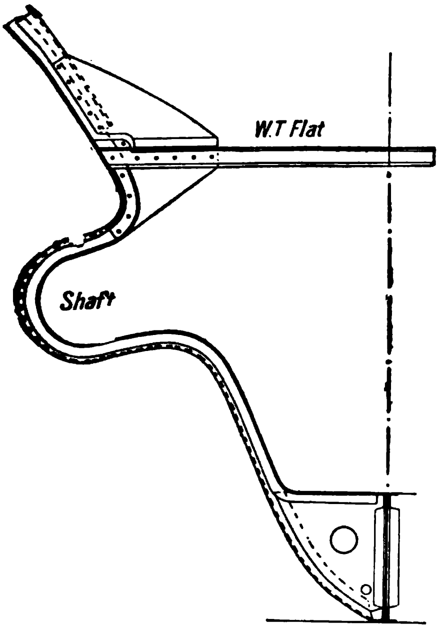

Face of post planed
Sections
Fore stern frame post
Bolts securing propeller brackets or spectacles to stern post
Shaft
Shaft
Spectacles for the support of the tail end shafts
Shaft
Plan of Spectacles
Stern post
Bottom of Stern frame

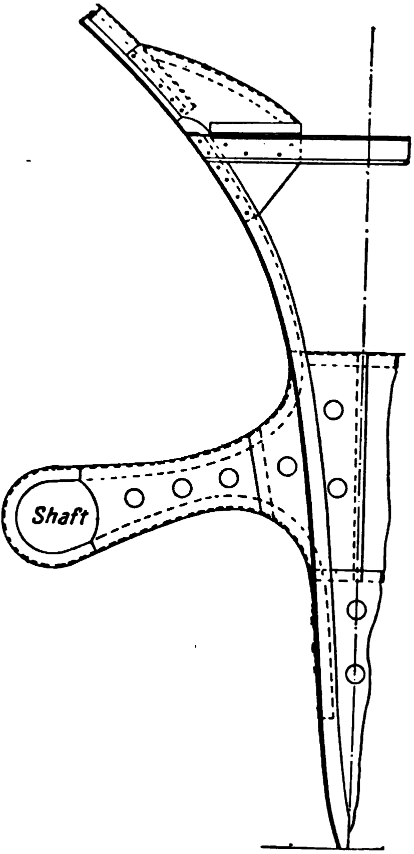
Fig. 157.—Stern Frame and Spectacles for Twin-Screw Steamer.


Watertight
Shaft
Tunnel

1st Position. Frames slightly bossed for shaft.


W.T Flat
Shaft

2nd Position. Frames considerably bossed for Shaft.



3rd Position. Frames carried down as usual, and separate framing bossed for shaft, and connected to the main framing as shown.

Fig. 158.—Showing Bossing of Frames in Twin-Screw Steamer at 3 intervals.

a forging, and in construction as illustrated in fig. 159. The rudder framework is plated on each side, and the space between the two plates is filled in with wood. The number of stays, stiffening the rudder in a fore and aft direction, vary with the size of the rudder, but one is usually placed opposite each gudgeon. Until within recent years, the rudder frame and stock was generally all one forging, but the awkwardness and inconvenience of unshipping a large rudder of this kind led to the adoption of the method illustrated in fig. 159, in which the upper rudder stock is an entirely separate forging, being connected to the main rudder itself by a bolted coupling, as shown.

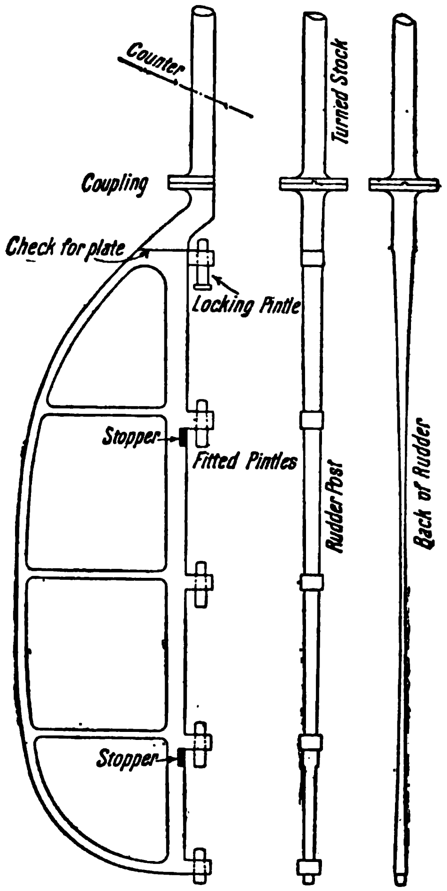

Counter
Coupling
Check for plate
Locking Pintle
Stopper
Fitted Pintles
Stopper
Turned Stock
Rudder Post
Back of Rudder

Fig. 159.—Frame Rudder.

The plate rudder is somewhat different. It consists of a main post usually coupled to the stock, and instead of a plated frame, a very thick plate formed to the required shape of the rudder is notched into the main rudder post, and supported at intervals with arms alternately on each side, which may be either forged into the post or shrunk on, as shown in fig. 160. The rivets connecting the side plates to the rudder frames in the case of frame rudders, and the thick plate to the arms in plate rudders,

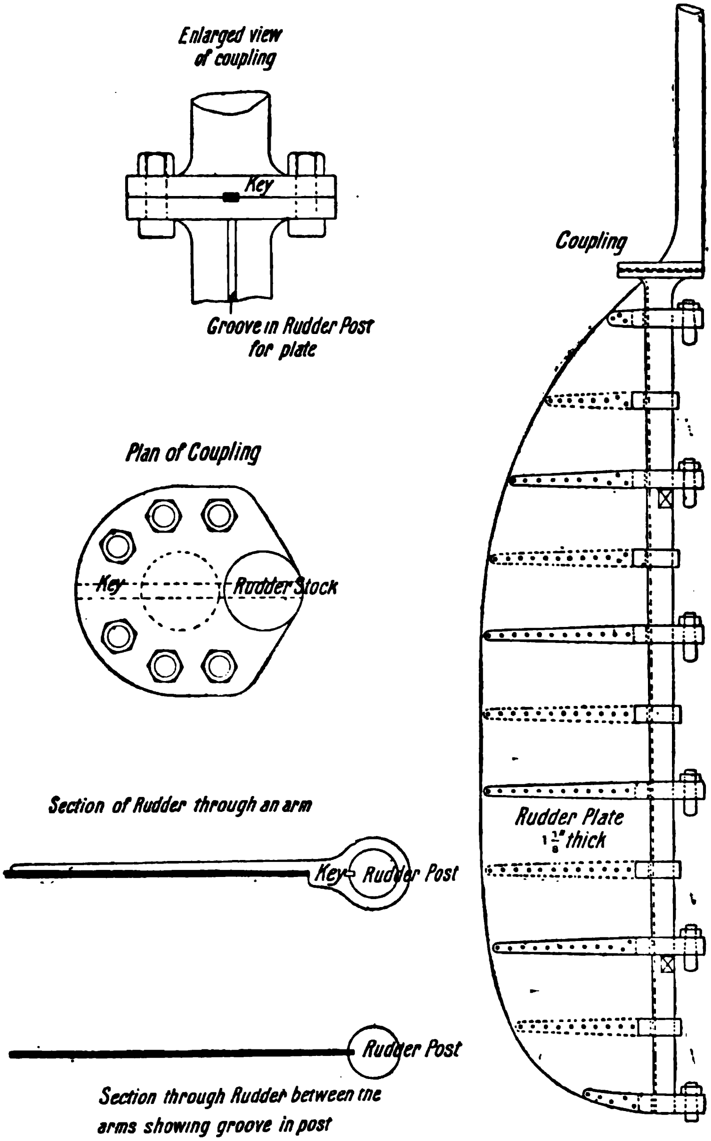

Enlarged view of coupling
Key
Groove in Rudder Post for plate
Coupling
Plan of Coupling
Key
Rudder Stock
Section of Rudder through an arm
Key
Rudder Post
Rudder Plate
1⅛" thick
Rudder Post
Section through Rudder between the arms showing groove in post

Fig. 160.—Plate Rudder, showing Arms shrunk on and keyed.

are usually spaced about five diameters apart. In the case of classed vessels, the size of rivets is specified by the registration society.

Stern Frame Gudgeons and Rudder Pintles.—As before stated, the gudgeons are forged on to a forged stern frame, or form part of the casting when of cast steel. The pintles on the rudder may either form part of the forging of the rudder frame, as shown in fig. 149, or, as is much more commendable, the pintles are fitted separately, and held in position by a nut with a check pin, which bears upon the head of the nut. Fitted pintles are illustrated in the rudder frames (figs. 159 and 160), and in the detailed sketches, 147, 148, 150, and 151.

A considerable amount of wear and tear must eventually take place owing to the incessant wearing action incurred by the rudder's movements when the vessel is under way. Numerous devices are adopted to prevent, or, at any rate, to make the wear and tear of such a nature that it can be repaired with a minimum of inconvenience and expense. When the pintles are forged to the rudder and fit into the gudgeons, as in fig. 149, with no other bearing surfaces than the bare metal of which they are made, repair would be no easy matter. But when the pintles are portable, and the gudgeons are bushed with lignum vitæ or steel or gun-metal, and the pintles bushed with brass after the manner illustrated in figs. 150, 151, 147, and 148, the wear and tear being confined to the bushes, these parts are renewed at comparatively little trouble and expense. When the weight of the rudder is transmitted through the bottom pintle to the stern frame, the wear and tear is naturally more rapid at this part. A good plan is to fit a round-topped steel disc, which is easily extracted and renewed, if a hole about one inch in diameter be drilled through the part of the stern frame beneath it, as shown in fig. 151, or, instead of the steel disc, a piece of lignum vitæ with the grain up is fitted into the bottom of this gudgeon hole, forming a good bearing for the bottom pintle.

To prevent the possibility of the rudder lifting by a heavy blow from a sea, it is common to fit one of the upper pintles with a forged head upon its lower end. This is called a locking pintle. (See fig. 150.)

As rudders are not usually allowed to turn more than an angle of 40° or 45° on either side, it is essential to have what are called stoppers, usually upon the gudgeons, and, if necessary, upon the rudder as well. Fig. 152 illustrates a rudder stopper, and the manner in which the gudgeon is formed so as to prevent the rudder turning beyond the desired angle. Two stoppers are usually fitted to each rudder, one upon an upper and one upon a lower gudgeon. (See figs. 159 and 160.) As the rudder stock tapers towards its lower extremity, a projection is sometimes made upon the rudder for the lower stopper, in order to get sufficient bearing surface for the check at the maximum angle.

Miscellaneous Details.

Continuity of Strength.—Nothing is of more vital importance in ship construction than that the continuity of all the principal structural parts be rigidly maintained. Wherever interruption takes place in the mode of construction in any part, which in itself would produce weakness, compensation must be introduced in such a manner that the continuity of strength will be assured. Thus :—

(1) Whenever a deck has a break in any part of its length, the one part being at a higher level than the other, as in the case of a main and raised quarter deck, the strength of the two parts must be united by overlapping the decks, side stringers, and increasing the thickness of the shell plating in way of the break. (See fig. 47.)

(2) Sometimes the bottom of a ship is built with ordinary floors, one part of the length, and the other with a double bottom tank. Wherever this occurs, the strength of the one must be scarphed into the strength of the other by carrying the keelsons on the ordinary floors into the tank for three or more frame spaces.

(3) Where decks or stringers are unduly weakened by openings through the deck, the strength must be maintained by increasing the thickness of the remaining plating, or by doublings. The same applies to the outside shell plating. (Figs. 143 and 144.)

(4) If stringers or keelsons are cut in way of bulkheads, their strength must be continued by connecting them to the bulkheads with large bracket plates.

(5) Where the transverse framing suffers interruption in its continuity from keel to gunwale, as at the margin plate of double bottoms, and sometimes where it passes through a watertight flat, the continuity of strength must be maintained by fitting large bracket plates (tank knees). (Figs. 47 and 78.)

Engine and Boiler Space.—The structural strength of the engine and boiler space needs special consideration. The great interruption which takes place in transverse strength owing to the cutting of so many deck beams in order to make the light and air openings through the decks, and the omission of so many hold beams, necessitates efficient compensation.

We have already seen how the deck ends are bound together and carried on the thick fore and aft coaming plates, but, in addition to this, a good number of extra strong continuous beams should be fitted wherever practicable in way of all the decks; and by converting these, where possible, into semi-box beams by uniting and covering them with plating, valuable strength is introduced. (See figs. 47, 48, 49, and 57.)

Especially in high-speed vessels is there the tendency to excessive vibration where this part is in any measure weak. To ensure against this, and to make the vessel as rigid as possible, not only are the reverse bars doubled on the floor plates under the engines and boilers, but the double bars are sometimes carried to the upper deck. To compensate for the loss of through-beams, it is also found to be very beneficial to the vessel to introduce several web frames into these spaces, and to thoroughly connect the stringers to them, as illustrated in fig. 48. In vessels having double bottoms, one or more additional intercostal girders should be introduced, at any rate under the engines, while the tank top plating in these spaces should be increased in thickness. On account of the rapid corrosion which shipowners find to take place, especially under boilers, the tank top plating is sometimes entirely dispensed with, and a form of construction similar to that shown upon fig. 161 is often adopted.

It will be noticed that the tank margin plate is carried continuously all fore and aft, while the keelsons shown must be scarphed into the double bottom. In some cases the double-bottom form of construction is carried continuously all fore and aft, with the exception that large openings are left through the tank top plating between the floors and the fore and aft girders, which are so large as to permit of easy and ready access at all times.

Masts and Derricks.—Masts are nowadays most frequently made of steel. In sailing vessels, where they are very long and of large diameter, there may be three plates in the round, with angle or tee bar stiffeners throughout their length.

In steamers, however, where the masts are usually short, carrying very little sail, two plates in the round are usually adopted, with or without stiffeners as the case may require. All masts should be doubled in way of the wedging at the upper deck for a length of about 4 ft. above and below the deck. The butts of the plates should be well clear of each other, and connected by either straps or overlaps. The edge riveting is usually single in steamers, while the butts above the upper deck should be treble riveted, and below, double riveted. Masts are secured, at the deck and heel by angle collars which may be riveted or wedged to the mast, and also by means of a good disposition of shrouds well connected to the sheer strake. See figs. 47 and 49.

In small vessels, or in vessels of moderate beam, the derricks for the loading and discharging of cargo are usually pivoted to the mast, as shown in fig. 66. Derricks always swing most easily when the masts are perfectly vertical, having therefore no rake. In large vessels of great beam, the length of derrick, to enable cargo to be swung clear of the vessel's side, would be so extraordinary that some means have become necessary to curtail their length within reasonable dimensions. This can be done by fitting special derrick posts to the deck, or by making the main ventilators of extra strength and height to serve as supports upon which the derricks may swing. (Fig. 165.)

But by far the best system of arranging the derricks is as shown in figs. 166 and 167.

In this arrangement, special tables are fitted to the mast at a height of about 7 ft. from the deck, and supported by stanchions and brackets as shown. The length of these tables transversely from the mast will depend upon the beam of the ship and the minimum length of derrick required. The advantage of relieving the derrick tables of as much thrust from the derricks as possible, by fitting a post from the deck to the derrick heel as shown, is obvious. Fig. 166 shows an arrangement of mast tops so designed that the pivoting point of the derrick topping lift is vertically above the derrick heel, thereby greatly facilitating the easy swinging of

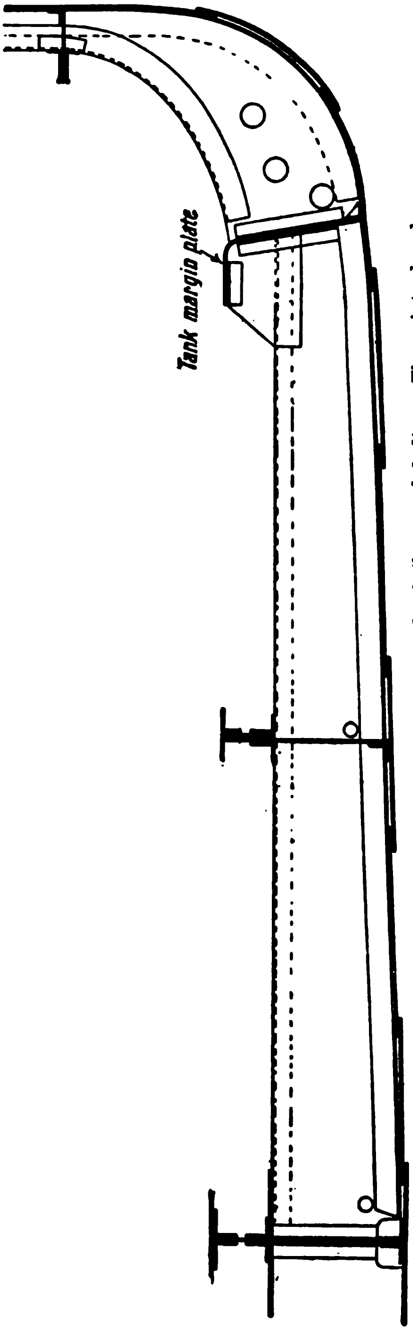

Tank margin plate

FIG. 161.—Cellular Double Bottom discontinued under boilers, and Ordinary Floors introduced.

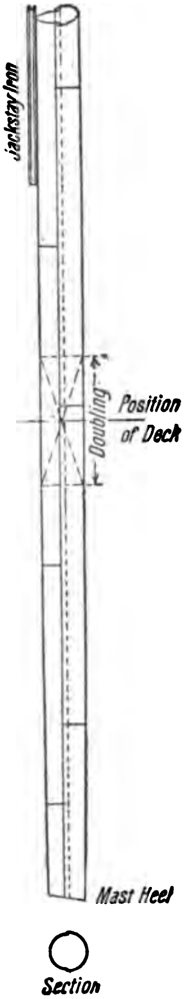

jackstay iron
Doubling
Position of Deck
Mast Heel
Section

FIG. 162.—Steel Mast.

the derrick. The derricks as illustrated in figs. 166 and 167 are such as are fitted to the steamer in fig. 72, which is designed for the rapid loading and discharging of cargo. Three derricks, it will be seen, are fitted to each hold. Fig. 166 shows the middle derrick resting upon a small table just above the larger tables, while fig. 167B shows a method of securing these derricks in a vertical position to the masts when the ship is at sea. The other derricks are laid in a fore and aft direction, and may rest either upon a poop, bridge, or forecastle end, or upon special stanchions.

The function of the middle derrick is to lift heavy cargo out of the hold, while that of the two side derricks is for lighter cargo only.

Fig. 163 illustrates a telescopic mast and fig. 164 a patent hinged topmast (Sidgwick's). Arrangements for lowering the topmasts are necessary in vessels which are required to pass under bridges, and which use such waterways as the Manchester Canal.

Panting.—The principal methods adopted to resist panting may be enumerated as follows:—

1. A closer spacing of frames.
2. Double frames.
3. An extra tier or tiers of beams with stringer plates on their ends well connected to the shell, or additional double angle, tee bar, or intercostal panting stringer may be introduced.
4. Floors of extra depth.
5. An increase in the thickness of shell plating, especially under the fore foot, where excessive thumping is experienced.
6. The middle-line keelson should be fitted intercostally as far forward as practicable.

Hatches.—The construction of the sides and ends of hatches has already been fully dealt with and illustrated in our remarks upon 'Beams,' p. 194. There is no doubt that many a ship has foundered through no other cause than the inefficient construction of hatches which have been unable to bear the weight of huge volumes of water which so often fall upon them when heavy seas are shipped. Not only should the coamings be of ample strength, but the hatch covers should be at least 3 in. in thickness, supported upon strong fore and aft, and, where necessary, transverse bearers. In the case of short hatches, one fore and aft middle line, and, if necessary, two side bearers, or 'fore and afters,' as they are technically called, should be fitted. These may be of wood, 6 in. or 8 in. square, fitted into shoes on the hatch end coamings, or they may consist of bulb angles, tee bulbs, etc. Where the hatches are of greater length, transverse assistance is given to the deck, and to prevent the hatch sides collapsing, by fitting transverse web plates, which should be stiffened on their upper and lower edges by angles or half-round iron, and fitted into slides, several methods of which are illustrated in fig. 115. Tarpaulins fastened to the hatch sides by cleats, battens, and wedges, are fitted to all vessels.

Deck Houses.—Deck houses for accommodation, etc., are frequently built entirely of steel with steel frames and beams. This certainly makes the strongest house. Where, however, they are built of wood, it is advisable

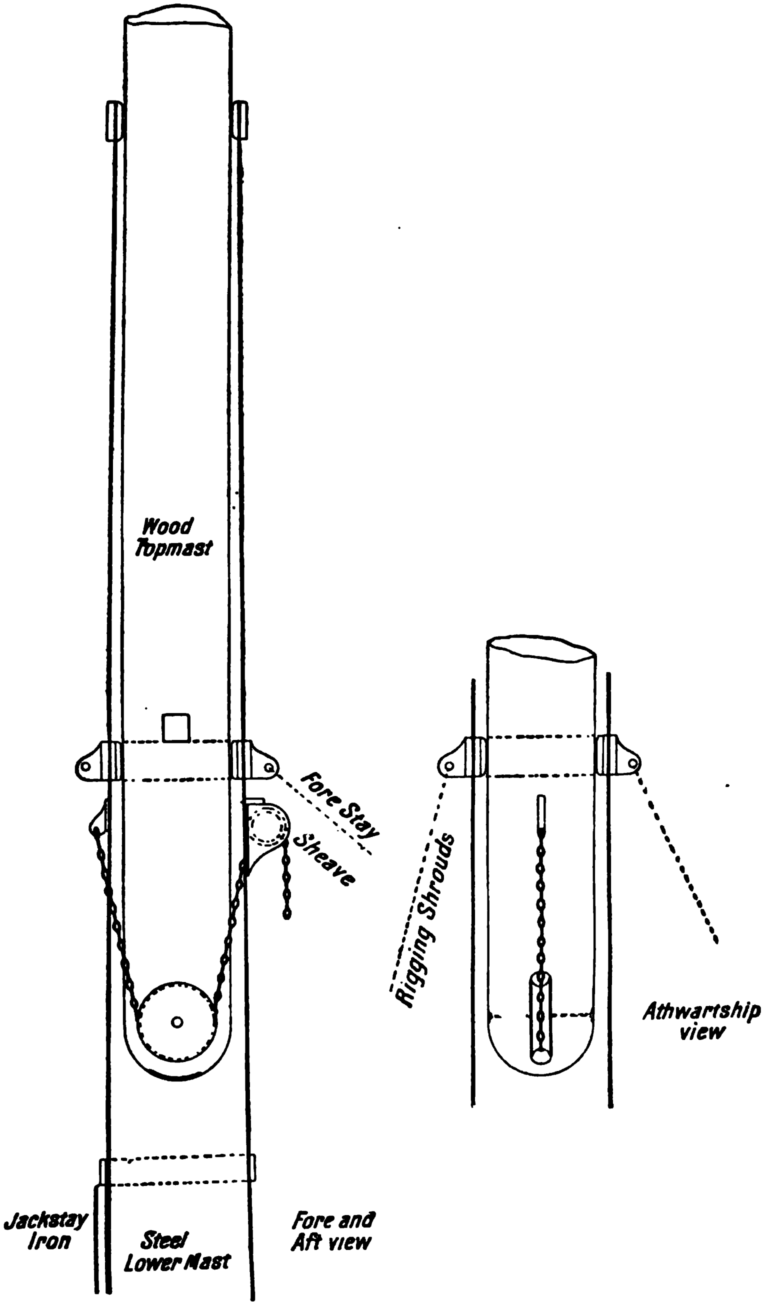

Wood Topmast
Fore Stay
Sheave
Rigging Shrouds
Athwartship view
Jackstay Iron
Steel Lower Mast
Fore and Aft view

FIG. 163.—Telescopic Mast. Showing arrangement for lowering Top Mast.

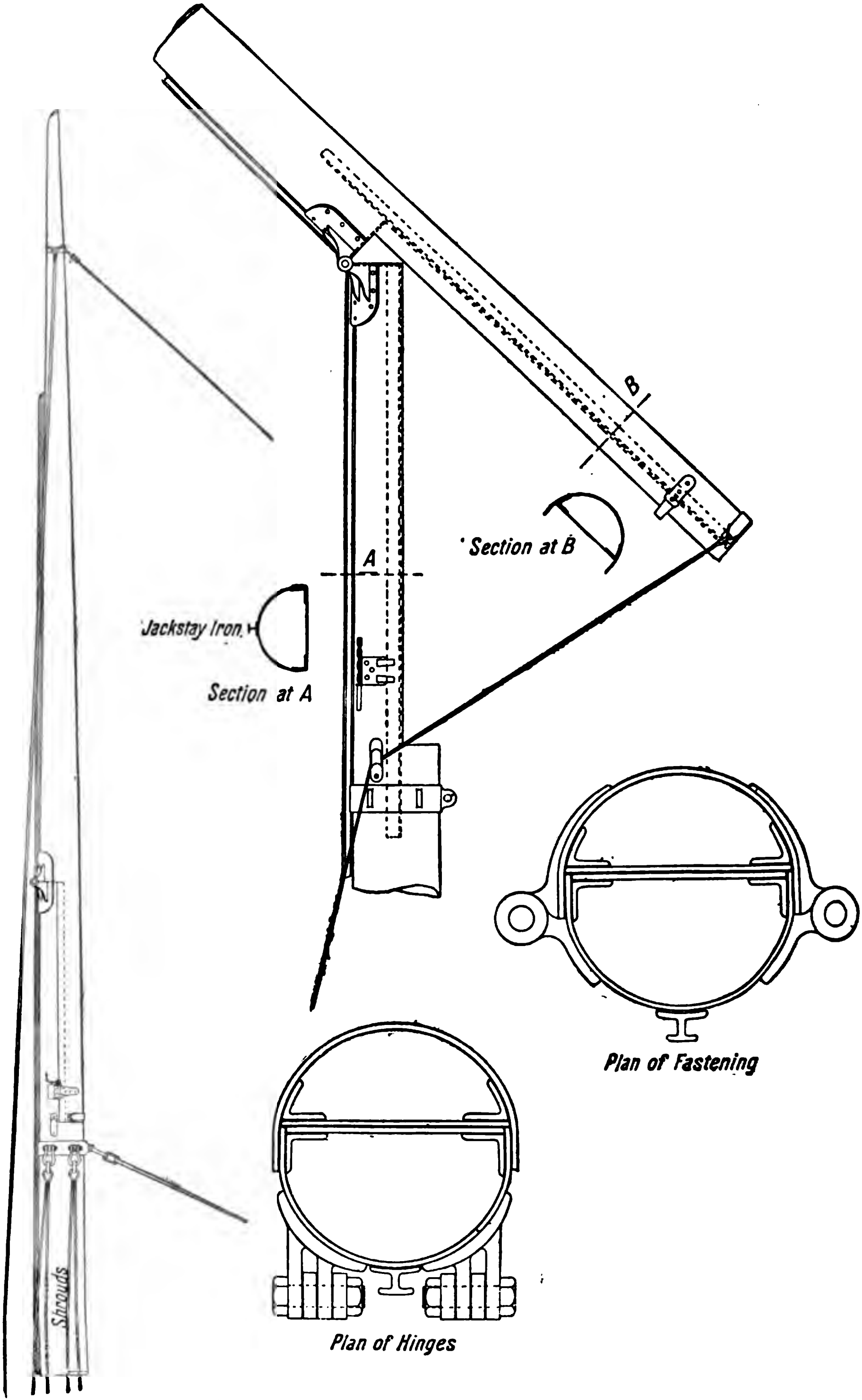

B
Section at B
A
Jackstay Iron
Section at A
Plan of Fastening
Plan of Hinges
Shrouds

FIG. 164.—Hinged Top Mast. (Sidgwick's patent.)

that they be framed with steel or iron bars, and have steel coamings well attached to a deck tie plate or to the steel deck if such is fitted. This

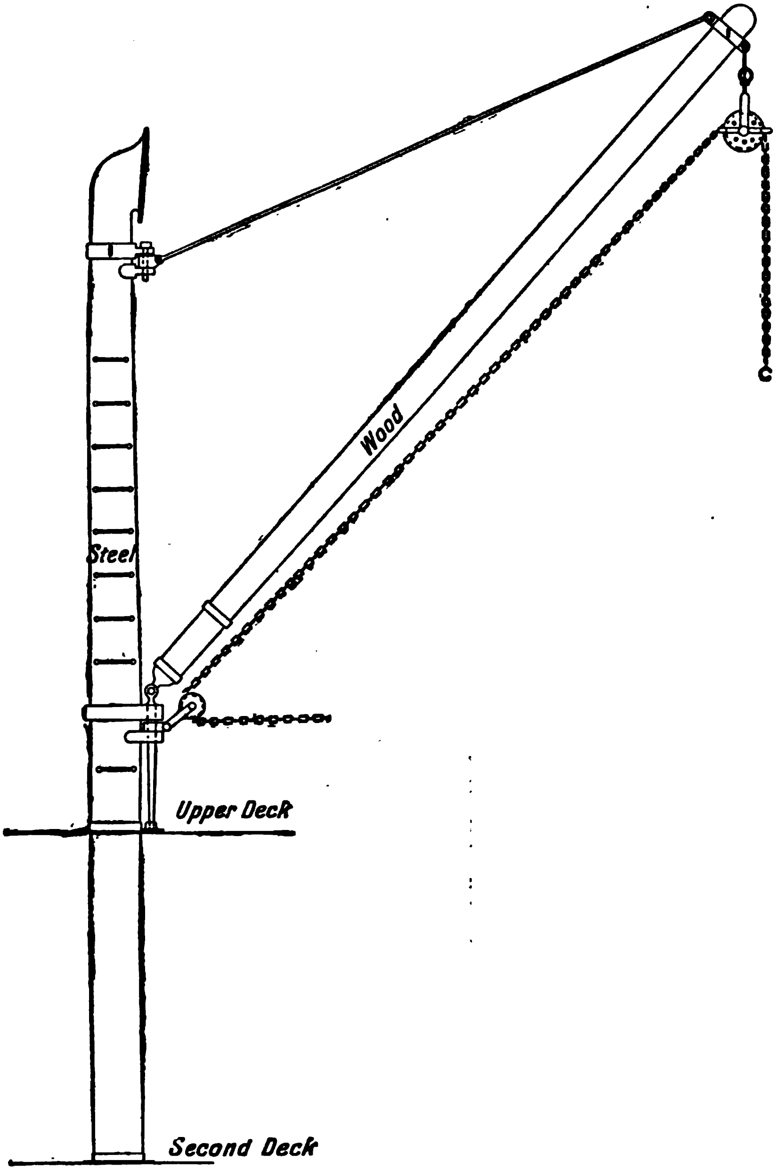


Fig. 165.—Derrick upon Ventilator.

affords a substantial framework upon which to lay the wood construction, and is illustrated in fig. 169.

Poop and Bridge Front Bulkheads.—All steel poop and bridge fronts

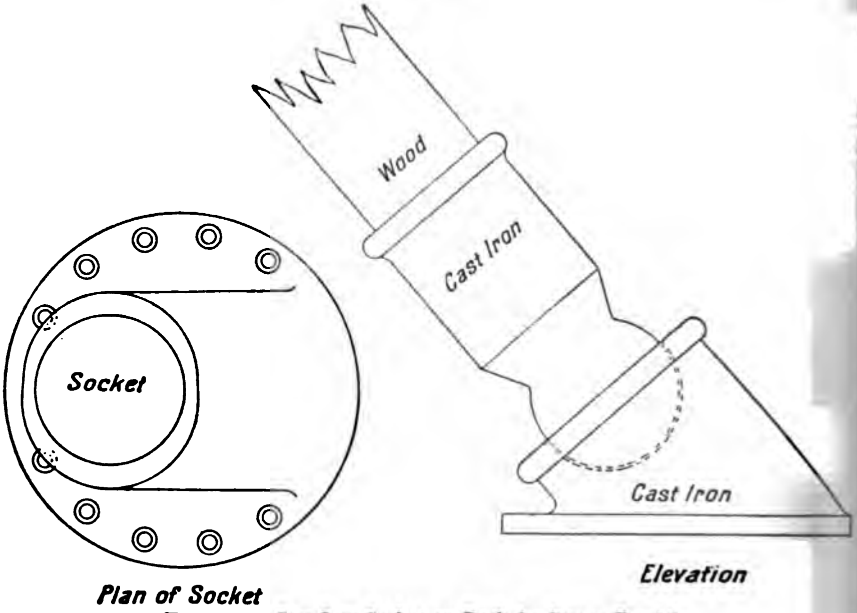

Wood
Cast Iron
Socket
Cast Iron
Elevation
Plan of Socket

Fig. 168.—Cast Iron Socket on Deck for Strong Derrick.

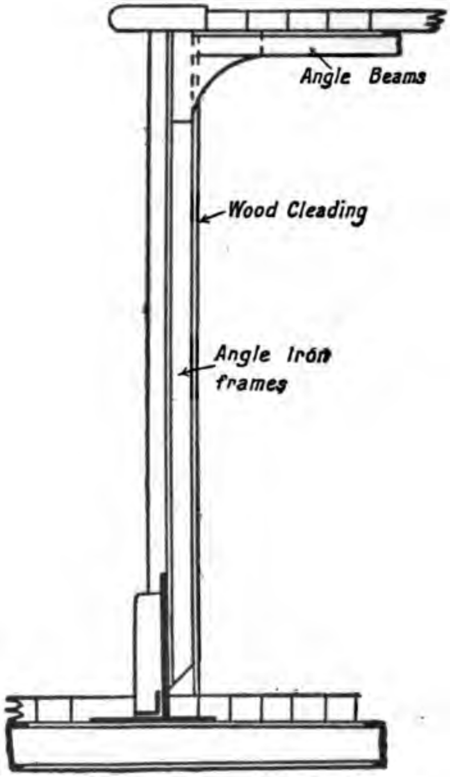
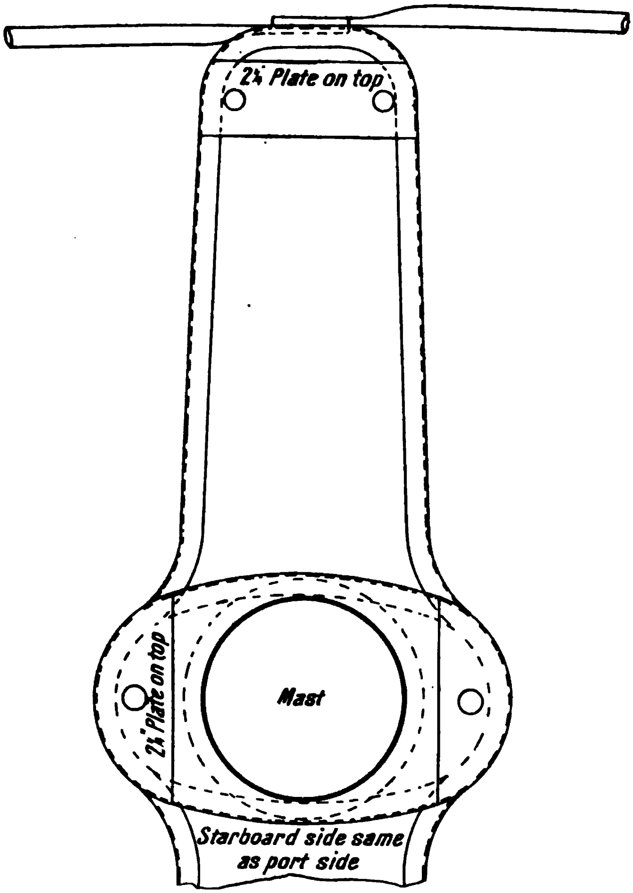

Angle Beams
Wood Cleading
Angle Iron frames

Fig. 169.—Composite Deck House.


2¼ Plate on top
2¼" Plate on top
Mast
Starboard side same as port side

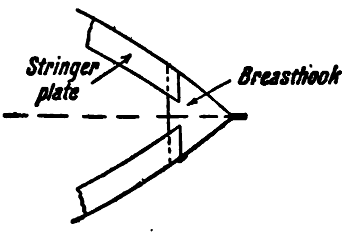
Plan of Derrick Table

should have thick coaming plates well connected to the deck. The upper plating may be somewhat thinner. The stiffening should be made by angle bars of at least the size of the main frames, spaced not more than 30 in. apart, with brackets top and bottom. Fig. 56 and remarks, pp. 129 and 130, further describe and illustrate the construction of these parts.

Tunnel and Casings.—The tunnel, by means of which the propeller shaft is encased, should be thoroughly watertight from the engine room bulkhead to the aftermost bulkhead with stuffing boxes upon each. As it is advisable to have the engine-thrust in free and easy communication with the engine room, the after engine room bulkhead is usually recessed for this purpose. The tunnel should be stiffened to resist the weight of the cargo which may rest upon it, by means of angles bent transversely round it on the inside. These should be spaced not more than 3 ft. apart. As far as possible, hold pillars should be kept off the tunnel, by arranging them zigzag one on each side. Where this cannot be avoided, double angle stiffeners must be fitted under the pillars. The tunnel under the hatchways should be sheathed with wood, or the plating increased in thickness, to protect it from blows from cargo in the operation of loading or unloading. It should be large enough inside to permit of easy access to all the shaft bearings. When the tunnel stands upon a centre keelson, the tunnel floor is usually laid on the top of the centre keelson, thus permitting more easily of being made watertight. (See fig. 79.)

Casings enclosing engine and boiler openings should be stiffened by angles or half-round iron on the inside, and if exposed to the weather, the strength must be sufficient to afford ample protection to the engines and boilers.

Breast Hooks.—All stringers, wherever practicable, should be carried all fore and aft, and united at the ends of the vessel by means of *breast hooks* thus. In large vessels, an extra breast hook should be fitted at the stem between each tier of beams for the further support of the shell plating.



Insulation.—Fig. 170 illustrates a system of insulation adopted in the holds and 'tween decks of steamers engaged in carrying dead meat, etc.

Bilge Keels.—A bilge keel is a projecting fin of some kind usually attached to the outside shell plating on the turn of the bilge, the resistance of which, as it oscillates with the rolling movements of the vessel, conduces to the desirable quality of steadiness or easiness in the vessel's motions, and reduction of the angle of inclination.

It may be constructed in several ways, but in mercantile steamers it usually consists of a bulb plate, 8, 10, or 12 in. in width according to the size of the vessel, riveted between double angles. It may be either riveted through the shell or connected by means of tap rivets. Another method is to connect the bulb plate to the shell by means of a single angle, or by means of a tee bar. But in the event of grounding upon the bilge keel or coming into contact with any kind of obstruction, the first method generally causes least injury to the ship, as the bulb plate simply buckles or bends over the two angles, and no injury is caused to the rivets through the shell. In either of the other methods, there is the danger of the tee bar, or angle, being wrenched at the root, and the caulking or riveting damaged and leakage ensuing. (See figs. 48, 64, and 71.)

Bilge keels should be placed so as to give the least possible resistance to propulsion, and kept as clear as possible from shell landings, tank side riveting, etc.

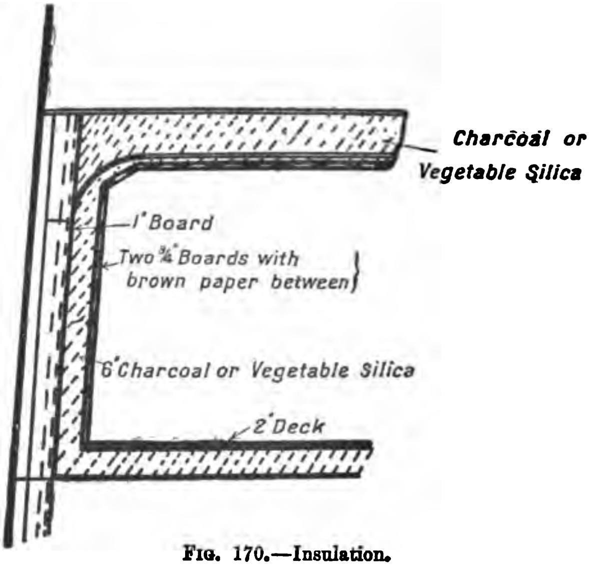

Charcoal or Vegetable Silica
1" Board
Two ¾" Boards with brown paper between
6" Charcoal or Vegetable Silica
2" Deck

FIG. 170.—Insulation.

Ventilation.

In every well-constructed vessel a great amount of thought is given to the subject of efficient ventilation, and though the arrangement for ventilation may be more complicated in a passenger vessel, yet it is of equal importance in a purely cargo one.

In every ship where a thoroughly efficient system of ventilation has been installed, there will be provided a free circulation of air in every compartment, whether it be saloon, cabin, or lavatory, occupied by passengers; in every crew space; in every hold space in which cargo of any kind has to be carried; in engine room, boiler room, and shaft tunnel; in bunkers, in every compartment used solely or temporarily for the carriage of water-ballast; in peak spaces; in store rooms, galleys, pantries, etc.; in short, *every* compartment in the vessel should be ventilated.

This is necessary, not only from a sanitary point of view, for the health and comfort of passengers, but because it is an absolute necessity for the engineers and stokers shut up in the bowels of the vessel, for the preservation of perishable cargoes, in order to rid hold and other spaces of obnoxious or poisonous and inflammable gases, and because good ventilation is as efficacious in the preservation of the material of which the vessel is constructed (iron, steel, wood, etc.), as the best patent composition ever put upon a ship.

Ventilation does not solely consist in making a certain number of inlets to, or outlets from, any particular space, as one would sometimes imagine by the way in which it is carried out, but it is the intelligent arrangement of such inlets and outlets by which they are so situated that fresh air is introduced and foul air is expelled. This is usually effected in ships by means of natural ventilation, though, in some cases, forced ventilation, by means of fan draughts, or even steam injections, is necessary, in order to rid certain spaces of the foul air which gathers in them.

Innumerable systems and patent arrangements for ventilation have been introduced and are in use, but in a work of this kind it is impossible to examine all these various methods, and we must therefore confine ourselves to the older method of natural ventilation, which may be very efficacious if well arranged.

The best known ventilator is the cowl-head (see fig. 171). It is essential that all ventilators situated upon the weather deck be sufficiently strong to endure without damage the force of heavy seas shipped on deck. In bad weather it is not very uncommon for deck ventilators to be carried away, and the cargo to suffer considerable damage, or discomfort to be brought upon passengers or crew, not to mention the possibility even of positive danger accruing from the continued ingress of water through such openings. Thus, in erecting cowl ventilators upon the weather decks, the coamings or lower plating should consist of thick plates (at least $\frac{6}{20}$ in.) connected to the deck by a correspondingly strong angle bar. These coamings should be at least 30 in. high. The upper part of the ventilator, which includes the cowl-head, is portable, and is usually made of thinner plating than the coamings, as in very bad weather, when much water is being shipped on deck, it is usual to unship this upper part, and fit into the top of the coamings the plate lid, which is shown in fig. 171, A, in a vertical position, where it is kept when not in use. To ensure that the ventilator be now thoroughly watertight, a canvas cover is lashed over the top of the coamings.

When these ventilators are intended to ventilate the hold space of a single deck vessel, the diameter ought to be regulated in accordance with the capacity of the space to be ventilated.

The coamings should be made of welded steel or wrought-iron plates.

The diameter of the cowl mouth should be large enough and so shaped as to take in as great a volume of air as possible (say, two or two and a half times the diameter of the coamings). The portable upper part of the ventilator, when fixed on to the coamings, rests upon an iron ledge upon the outside of the coamings, as shown in fig. 171, A; or it may come right down and rest upon the vertical flange of the deck angle. There should be at least two cowl ventilators to each hold, one at each end of the space, and in such positions that they may efficiently act, one for the inlet of fresh air, and the other for the outlet of the hold space air, which is expelled. When these ventilators are situated near to, or against, forecastle fronts, bridge ends, poop fronts, or any other deck erection, they should extend to a height such as will bring the cowl mouth above the top of these erections. Their extreme length necessitates that they be supported by means of stays, either to the deck or to the erections near which they are situated. When a vessel has two or more laid decks, it is usual to ventilate the hold and main deck spaces in a manner similar to that shown in fig. 171, B. The diameter of the ventilator coamings upon the uppermost deck is made sufficiently large to ventilate the whole of the space below the upper deck, supposing no 'tween decks existed. But as 'tween decks do exist, the area

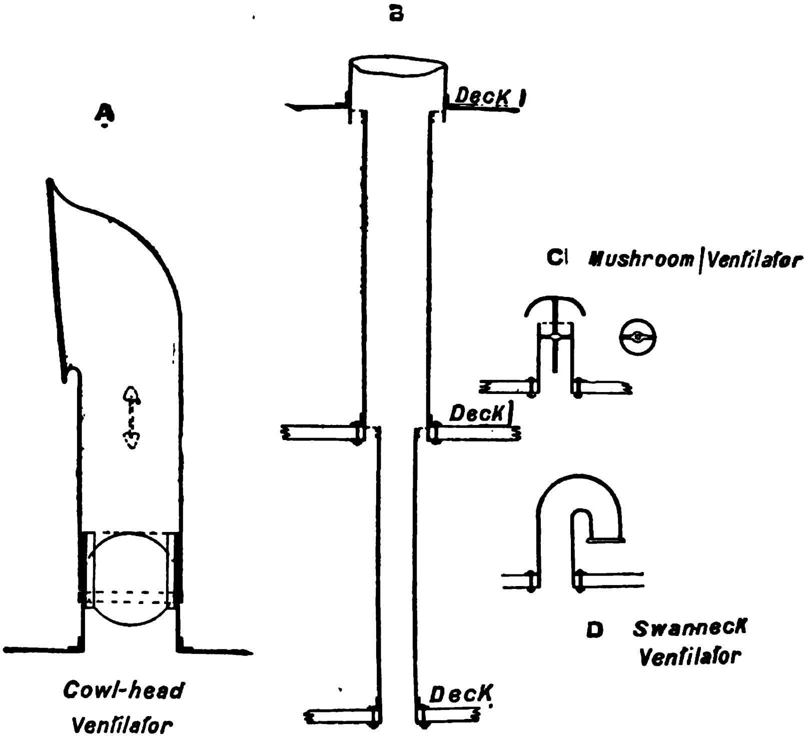


Fig. 171.—Ventilators.

of the ventilating opening on the upper deck is reduced by the insertion of a tube leading to the second 'tween decks, the diameter of which is supposed to be large enough to ventilate the lower 'tween decks and hold space. But as the hold space is an entirely separate compartment, the area of the ventilating opening in the upper 'tween decks is again reduced by the insertion of a ventilating tube from the hold space, the diameter of which is in proportion to the volume of such space. It will be evident that while one ventilator at the end of each hold space may be sufficient in a small single deck vessel, a greater number of ventilators will be required in large vessels with one or more 'tween decks and huge hold spaces. (For the ventilation of steamers carrying oil in bulk, see Chapter VI., Section 2.)

While it may be advantageous to ventilate both forecastles occupied by crew, and cabin accommodation in other parts of the vessel by means of cowl-head ventilators where the spaces are of considerable size, sufficient ventilation can be obtained in small cabin spaces, galleys, pantries, lockers, store-rooms, lavatories, etc., by means of swan neck and mushroom top ventilators (see figs. 171, D and C), assisted by louvre openings in the doors. Most of these spaces have the additional advantage of hinged scuttles, which in fine weather may provide an abundant flow of fresh air, and in bad weather may be secured and made thoroughly safe by their solid hinged plate dead-lights.

One of the parts of the vessel which needs particular attention in designing the ventilating arrangements is the engine room. This space is often sadly neglected, as those who have had any sea experience of these vessels know. The recesses in these spaces caused by pocket bunkers, engine room store, etc., and the fact that the opening through the decks is often very narrow, with consequently large flat areas of deck overhead, tends to the harbour of a considerable amount of stagnant air, owing to the ventilators, as a rule, being inserted through the top of the casings, and failing to rid the space of the obnoxious air in the engine room wings. In addition, engine rooms often get unbearably heated, owing to the proximity of the boilers. The boiler room also needs ventilating, and this is largely effected by the iron gratings on the top of the casings, and cowl-head ventilators of very large diameter. One or more cowl-head ventilators ought to be fitted into the tunnel, one as far aft as possible. The other spaces previously mentioned may be ventilated by one such ventilator as illustrated in fig. 171, C and D.

Pumping.

Nothing in the equipment of a vessel is of greater importance than a well-planned and thoroughly efficient arrangement of pumping. This is essential for many reasons, all of which ought to be thoroughly considered and thought out in the design of such an arrangement.

In any vessel there is always a possibility of water finding its way into the interior of the hull below the weather deck. This may be due to damage from collision, leakage, damage to deck fittings in heavy weather, drainage from wet cargo, heavy sweating in the inside of the shell plating, decks, etc., especially where ventilation is inefficient, drainage from scuppers, etc., etc.

The pumping installation should be capable of speedily ejecting all such water, excepting in cases where collision has made an opening so large that for any pump to cope with the inflow is impossible.

In sailing vessels where there is no steam power on board, all such pumping has to be effected by manual labour. Where the vessel has much rise of floor, so that even under considerable list to port or starboard, the water still gravitates to the middle line, there should be at least one hand pump to each hold compartment.*

In order to allow water to drain from one hold compartment to another, it is permissible to fit sluice valves to each bulkhead (when more than one bulkhead is fitted). On no account should a sluice valve be fitted to the collision bulkhead.

No sluice valve should be fitted to any watertight bulkhead unless it can be reached at all times, on account of the possibility of chips or rubbish getting jammed into the opening and preventing the valve from closing.

To reach the sluice valves upon watertight bulkheads, either a wooden or plated trunk-way must be fitted from the deck above, sufficiently dust-tight to prevent dirt, grain, etc., finding their way from the hold to the valves. All rods working the sluice valves should extend to the upper deck, and be clearly marked with a brass plate cover, so as to be easily found, and fitted with an indicator to show when shut and open.

To ascertain the depth of water in any compartment in any possible condition, a sufficient number of sounding pipes should be fitted. The depth of such water is ascertained by means of a sounding rod lowered inside the pipe. As the frequent thumping of such rods would be likely to eventually perforate the shell plating, a small doubling plate should be fitted under each sounding pipe.

If a tube were inserted in a basin of water, and the air sucked out of the tube, the water inside the tube would rise to a considerable height above the level water in the basin. This is due to the atmospheric pressure upon the surface of the water in the basin, and the fact that this pressure has been wholly or practically taken from the water at the bottom of the tube. Were the tube long enough, and the vacuum so produced absolutely perfect,

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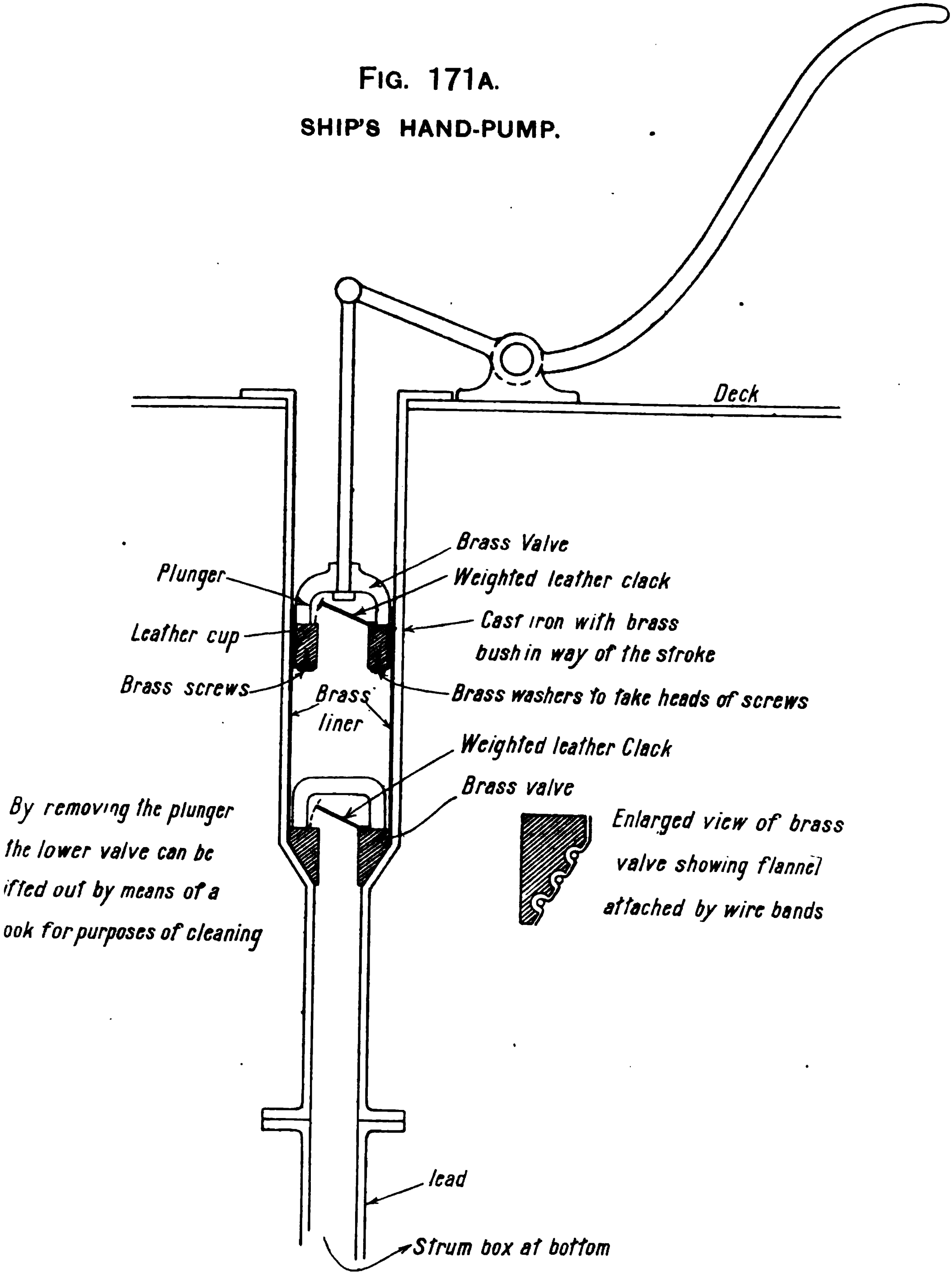
* It may be pointed out that in sailing ships only one bulkhead is usually fitted, viz., the collision bulkhead, and this therefore greatly simplifies the pumping arrangement. As a rule, one pair of pumps to this main hold space is considered sufficient.

These suctions are led from the pump well, which is usually situated just abaft of the main mast. Access is obtained to this well, whenever necessary, by a wooden trunk-way fitted from the weather deck to the bottom of the ship.

FIG. 171A.

SHIP'S HAND-PUMP.


Deck
Brass Valve
Plunger
Weighted leather clack
Leather cup
Cast iron with brass
bush in way of the stroke
Brass screws
Brass
liner
Brass washers to take heads of screws
Weighted leather Clack
Brass valve
By removing the plunger
the lower valve can be
ifted out by means of a
ook for purposes of cleaning
Enlarged view of brass
valve showing flannel
attached by wire bands
lead
Strum box at bottom

the water in the tube would rise to a height of about 34 ft., the weight of such a column of water being equal to the atmospheric pressure upon every unit of area on the surface of the water in the basin, equal to the sectional area of the tube.

The principle of the manipulation of the hand pump is identical with the foregoing illustration. First of all, there is a long suction tube from the bottom of the vessel up to the pump chamber. The action of the bucket, which is worked by a handle on the deck, is to first pump the air out of the pipe, immediately upon which the water ascends. Were a perfect vacuum produced, it would rise, as previously stated, to a height of about 34 ft., but as it is practically impossible in such pumps to get an absolute vacuum, it is safer never to count upon the water rising above 24 ft. As hand pumps are usually worked from the upper deck, the suction chamber should be deep enough to ensure that the bucket is not more than 24 ft. above the bottom of the hold.

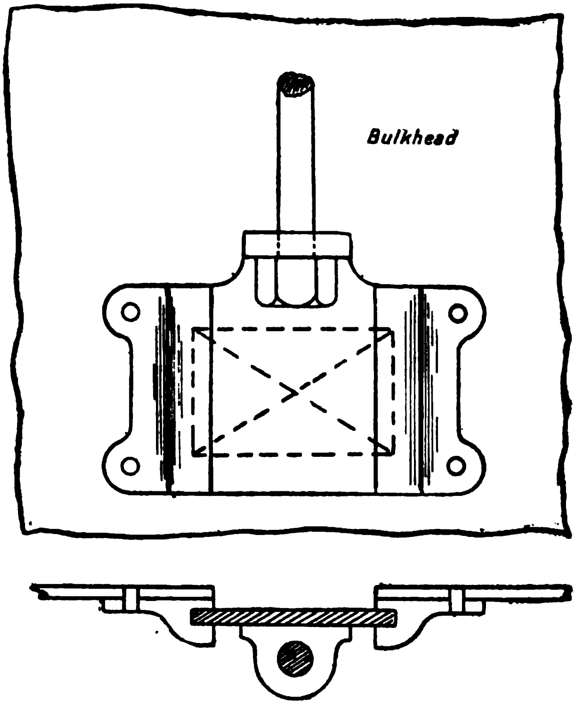


FIG. 172.—Sluice Valve.

A rose, strum box, or suitable mouthpiece is usually fitted to the lowest extremity of the suction pipe, to prevent any solid matter being drawn into the pump. As a considerable thickness of cement is commonly laid on the inside of the bottom shell plating for purposes of preservation, the cement ought to be dished out in way of the strum boxes so as to bring the bottom of the suction pipe below the level of the cement, and thus as nearly as possible eject all water from the compartments (see fig. 173). The necessity for an ample number of drain holes through the floor plates (or limber holes), to allow the water to reach the pumps, will now be apparent.

A pump is now in existence (Downton's) by means of which several suctions may be led into one suction chamber, and water pumped from any compartment. In sailing vessels having a donkey boiler, these pumps should be arranged so that they may be worked, if necessary, from a steam winch.

Steam Vessels without Double Bottoms.

Screw and paddle vessels have the great advantage of possessing steam power, which is utilized in pumping from the various compartments. Steam vessels without double bottoms should have at least one hand pump and one steam pump fitted in each hold when the rise of floor is considerable.

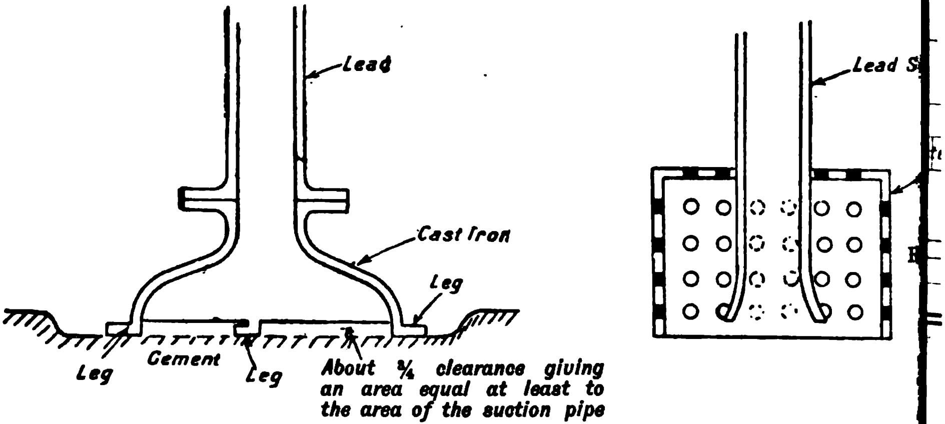

Lead
Cast Iron
Leg
Cement
Leg
Leg
About ¾ clearance giving an area equal at least to the area of the suction pipe
Lead S

Fig. 173.—Mouthpiece for Suction Pipe with three legs resting upon the cement, which is dished ou

When there is very little rise of floor, three steam-pump suctions—one as near the centre line as possible, and one in each wing—and at least one hand pump, should be fitted into each hold compartment. If the vessel has fore and after peak water-ballast tanks, a separate steam-pump suction should be led to each. When water is not carried as ballast in these compartments, a hand pump only is required in the fore peak.

No sluice valve must be fitted to the collision bulkhead under any circumstances; indeed, no sluice valve must be fitted to any bulkhead which bounds a water-ballast tank. If the after peak is not intended for the carriage of water-ballast, a sluice valve may be fitted in order to allow any water to reach the pumps in the after hold. The engine and boiler space should be fitted with at least three steam-pump suctions, one at the centre, and one in each bilge, and the Board of Trade requires one hand pump.

Steam Vessels with Double Bottoms. (See fig. 174.)

Before dealing with the pumps, the nature of all the spaces or compartments which exist along the bottoms of vessels with double bottoms for the carriage of water-ballast ought to be thoroughly understood.

The double bottom should at least be divided into watertight compartments agreeing with the number of the watertight bulkheads. But this division is often exceeded in practice. (See figs. 49, 66, and 174.)

Hence it is necessary that steam pumps should draw from each of these compartments. But at the wing extremities on the outside of double bottom tanks, there are the bilges into which drainage from cargo, scuppers, sweating, etc., may find its way, and pumps must be provided to get rid of such water.

It is usual and advisable to arrange for about two frames spaces at or near the after end of the engine and boiler space to act as a well into which bilge water may drain. A cock or sluice valve may be fitted through the bulkheads in way of the bilges at each end of this space so as to allow bilge water in the adjacent holds also to drain into the engine-room well. As before stated, such sluice valves or cocks should be always accessible.

The well is in all respects constructed like the double bottom elsewhere, excepting that the floor at each end of it is watertight, and several holes, 3 in. or more in diameter, are punched through the tank margin plate through which the bilge water flows into the well, or in lieu of this a better arrangement is to fit a non-return valve on the margin plate. When such a well exists, one steam-pump suction should be led as near the middle line as possible, and one in each bilge.

The main and donkey pumps should be arranged to draw from the fore peak, and the after peak also if used for water-ballast, from double-bottom tanks, wells, bilges, and from hold spaces in vessels without double bottoms. The donkey pump should have a separate bilge suction in the engine room. The steam suction pipes from the various compartments, on reaching the engine room, are led into combined valve boxes or chests, which are in turn connected to the pumps. Fig. 175 shows such a valve chest, and the donkey pump, which is of double acting type. As shown in the diagram, when it is desired to draw from any particular compartment, the valves to suctions for other compartments can be closed by the valves shown.

A well, similar to that just described for the engine room, is usually arranged at the after end of the after-hold space into which bilge drainage finds its way. A steam pump suction is therefore necessary for this space also.

Adjacent to this well, another well is usually constructed exclusively for drainage from the tunnel, which in its turn also requires a separate suction, which may be connected up to the hold well suction by a valve box somewhat similar to that illustrated in fig. 175, and which is manipulated from the inside of the tunnel.

A sounding pipe should be fitted on each side of all ballast tanks with the necessary doubling plate under each, as previously pointed out.

To allow for the exhaust of air in all water-ballast tanks when being filled up, a sufficient number of air pipes should be led to the upper deck, which, if made of 5 in. or 6 in. diameter, instead of 2½ in. or 3 in. as usually fitted, may conveniently, and with great advantage, add to the preservation of the structure, if made to act as ventilators.

Sufficient limber holes should be punched through all floor plates and tank knees, increasing in number towards the suctions, to allow for an ample flow of water to reach the pumps.

All tank floor plates should be perforated with circular holes near the upper extremity, to act as air passages, and for a similar reason the packing pieces under outside strakes of tank top plating should be kept a little short.

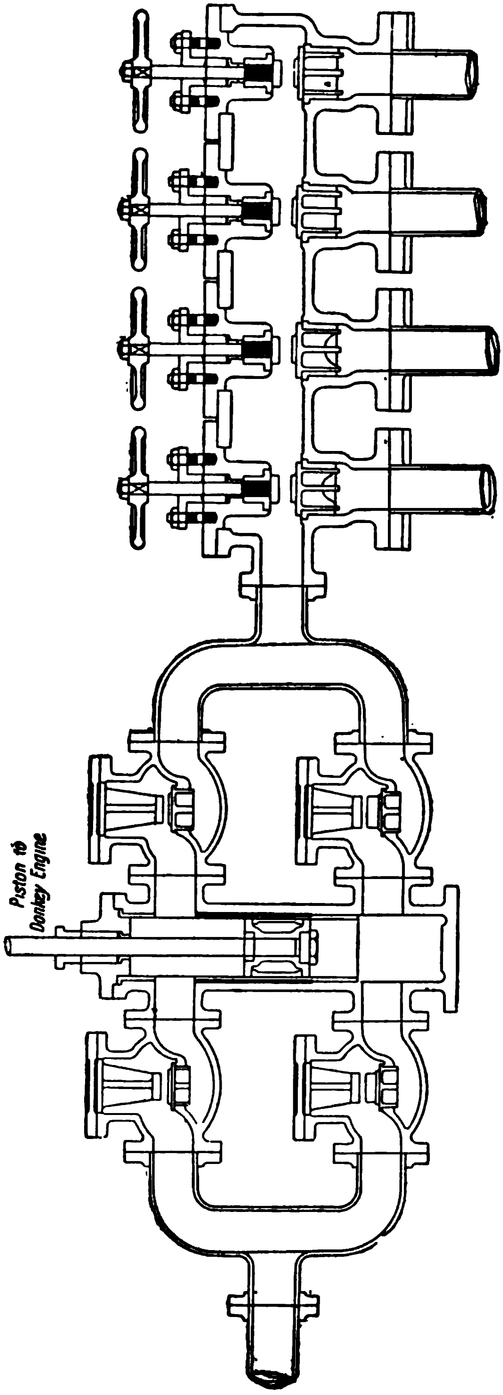


FIG. 175.—Bilge Suction Valve Chest, showing non-return Valves.

Hand Pumps, Steam Suctions, etc.

The following tables taken from Lloyd's Rules will give some idea of the minimum sizes required for pipes to hand pumps and steam suctions.

Tonnage under Upper Deck.	Hand Pump in Holds.	
	Diameter of Barrel.	Diameter of Tail Pipe.
	in.	in.
In vessels under 500 tons, . .	4	2
„ „ of 500 but under 1000 tons,	4½	2¼
„ „ „ 1000 „ „ 2000 „	5	2½
„ „ „ 2000 and above, . .	5½	2¾

Tonnage under Upper Deck.	Engine Room Centre Suction, Separate Donkey Suction, and Hold Centre Suctions.	Wing Suctions in Holds where no Centre Suctions are fitted, and Wing Suctions in E. and B. Room.	Wing Suctions in Holds where Centre Suctions are fitted.
	in.	in.	in.
In vessels under 500 tons, . .	2	2	2
„ „ 500 tons and under 1000 tons	2¼	2	2
„ „ 1000 „ „ „ 1500 „	2½	2¼	2
„ „ 1500 „ „ „ 2000 „	3	2¾	2¼
„ „ 2000 „ „ „ 3000 „	3½	3	2½
„ „ 3000 „ and above, . .	3½	3½	2¾

Launching.

One of the most important events in the history of a ship is the launch,—important, not only because this is her introduction to the element upon which the work of her life will be performed, but because, in the transit from land to water, unless the greatest care and caution are exercised, results of a most disastrous nature may accrue. Instances are on record when the damage received in launching has distinctly contributed to the loss of the vessel at sea, and many a ship has been so injured as to cost her builders thousands of pounds to repair.

The strength of the launching cradle and standing ways, the earth foundation as well as the declivity, length and camber of the standing ways, are all features in the carrying out of a launch which contribute to the success of this operation.

In shipyard practice the laying of the ways was, and is still, in some of the smaller establishments, left in the hands of the foreman shipwright, whose experience guides him in fixing the declivity, etc., necessary for any particular vessel. But with the vast increase in the sizes of vessels in recent years, the launching particulars are fixed in the ship drawing office, where the whole matter is considered and investigated, and the calculations involved carried out.

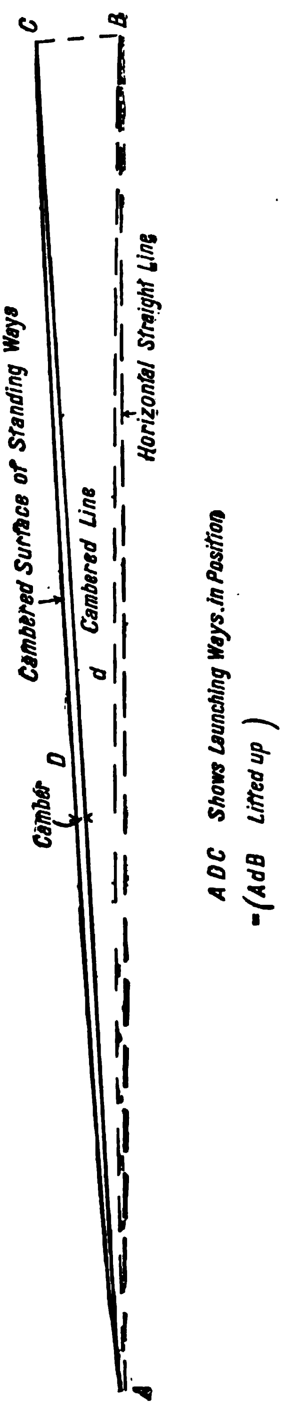

C
B
Cambered Surface of Standing Ways
Horizontal Straight Line
Cambered Line
d
D
Camber
A
ADC Shows Launching Ways in Position
(AdB Lifted up)

FIG. 176.—Diagram showing straight and cambered launching ways.

One of the greatest dangers in launching a ship is, that in the event of there being too little water on the ends of the ways, she may tilt after her centre of gravity has passed the ends of the standing or fixed launching ways. The fore end of the vessel would then be lifted entirely clear of the sliding ways, and the whole weight of the vessel (less the buoyancy of the water-borne portion of the ship) would then be resting upon the extreme end of the fixed ways, and these, being made of wood, might collapse under the pressure. Moreover, there would be nothing to prevent the vessel slewing across the launching ways by any slight wind or tide, and even leaving the launching ways altogether, bringing about a catastrophe of the most serious nature. (See also Chapter VII., p. 177.) The enormous pressure experienced by the bottom, when a vessel tilts, is sometimes sufficient to crush in the plating and do other damage. The ways may be flat or hollow (see fig. 96), and the breadth of the ways for a merchant vessel about 300 ft. long would generally be from about 15 to 18 in.

The usual declivity of the keel is about $\frac{1}{2}$ in. or $\frac{9}{16}$ in. per foot of length, and is a perfectly straight line. The declivity of the standing ways may be either perfectly straight, or cambered in the direction of the length. The latter method is commonly adopted.

Fig. 176 shows what is meant by 'camber.' Let A B be a straight horizontal line, representing the length of the launching ways. Upon it construct an arc of a circle, A d B, having a round or camber of, say, 18 in. Now lift A B up to A C, so that it has the declivity desired for the launching ways. A D C will be the form of the surface of the standing ways. The camber varies from 9 in. to 12 in., though for special types of vessels it may be lower or higher than these limits.

It will now be seen that a tangent upon the upper half of the arc of the launching ways must be at considerably less declivity than the tangent upon the lower half of the ways. Hence, in providing particulars of the launching ways, two declivities are usually given when the ways are cambered. The usual declivity of the standing ways runs about ½ in. per foot on the fore part of the ways, to ¾ in. or more towards the ends.

The mean pressure per foot upon the sliding ways ranges up to three tons, seldom over, the average being two tons.

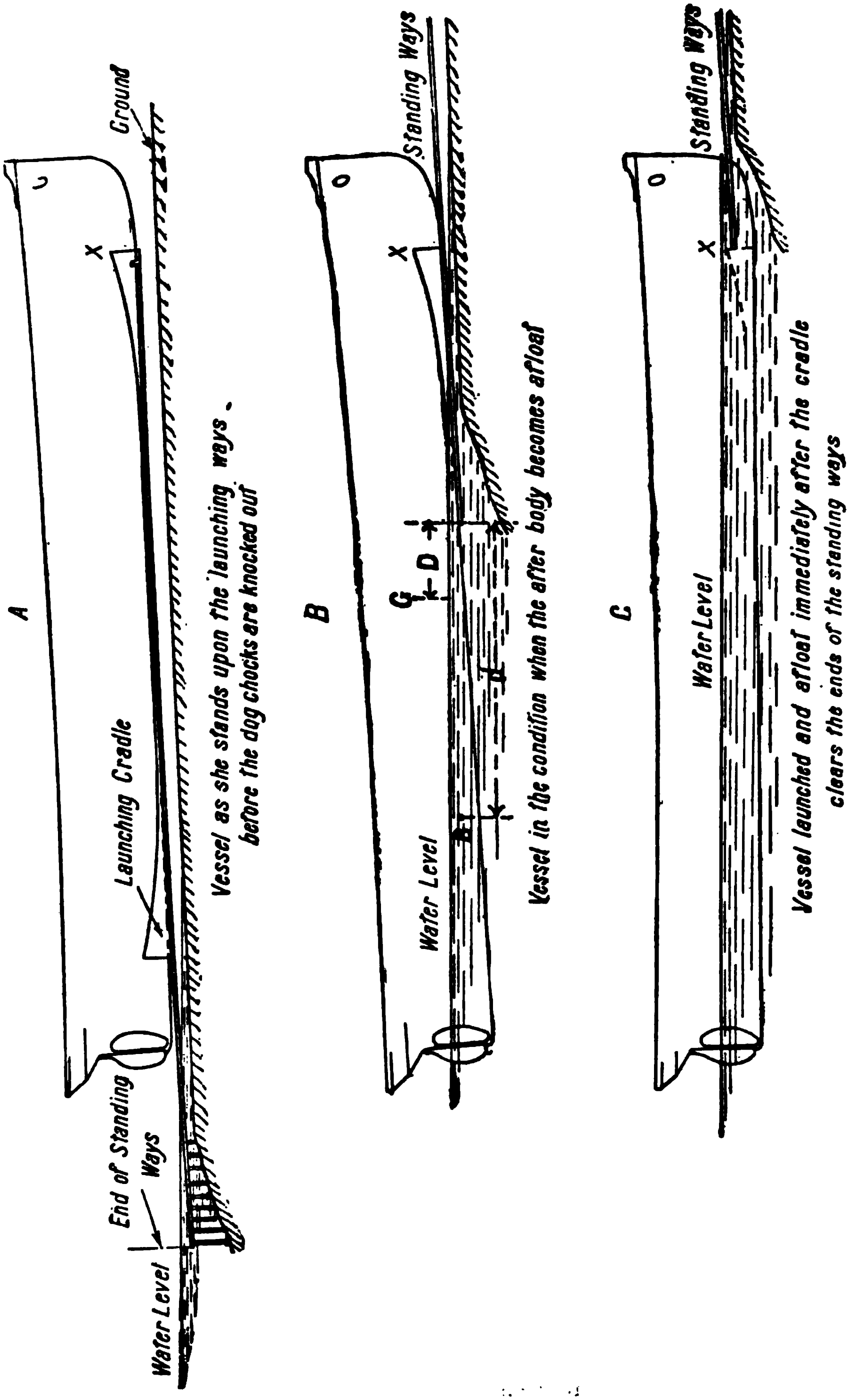
Experience is invaluable in shipyard practice, but the very best is liable to fail under exceptional circumstances, hence launches are not always as successful as they might have been had the vessel's condition been tested by calculation before the operation of launching was performed. Everyone who has seen a ship launched has observed that at the moment she begins to move after the dog chocks have been knocked out at the fore end, her weight over the whole of the length bears on the launching ways. But as she travels, her after end passes over the end of the ways, enters the water, and eventually becomes afloat, while the fore end bears upon the fore end of the launching cradle. (See fig. 177.)

The point at which the after end of the vessel becomes water-borne (the transition stage between 177, A, and 177, C, namely, 177, B) will occur when the moment of the ship's weight about the fore end of the launching cradle (the sliding ways), X in fig. 177, is exactly equalled by the moment of the buoyancy of the immersed volume of the vessel about the same point X.

The moment of weight is obtained by multiplying the vessel's weight in tons by the distance of her centre of gravity from the fore end of the cradle (X, in fig. 177), and the moment of buoyancy is found by multiplying the buoyancy in tons of the immersed volume by the distance of its centre of buoyancy from the fore end of the cradle also.

Supposing a ship to be 300 ft. long, her weight on the ways to be 1500 tons, and the distance from her centre of gravity to the fore end of the launching cradle to be 130 ft., then the moment of weight would be $1500 \times 130 = 195{,}000$ ft. tons. When this amount of buoyancy moment exists, it is known that the after end of the vessel is afloat, making allowance for the fact that slightly more immersion is necessary in order to overcome the ship's momentum, which causes her to travel a little further down the ways before her stern lifts.

When the aft end of the vessel enters the water, her weight will be partly borne by the water, and partly by the launching ways. The amount of support afforded by the water is the displacement, and the difference between the displacement and the total weight of the ship represents the weight borne by the launching ways. Through not realizing the amount of this pressure upon the fore end of the sliding ways, some-


A
Ground
X
Launching Cradle
End of Standing Ways
Water Level
B
Standing Ways
X
G
D
Water Level
C
Standing Ways
X
Water Level

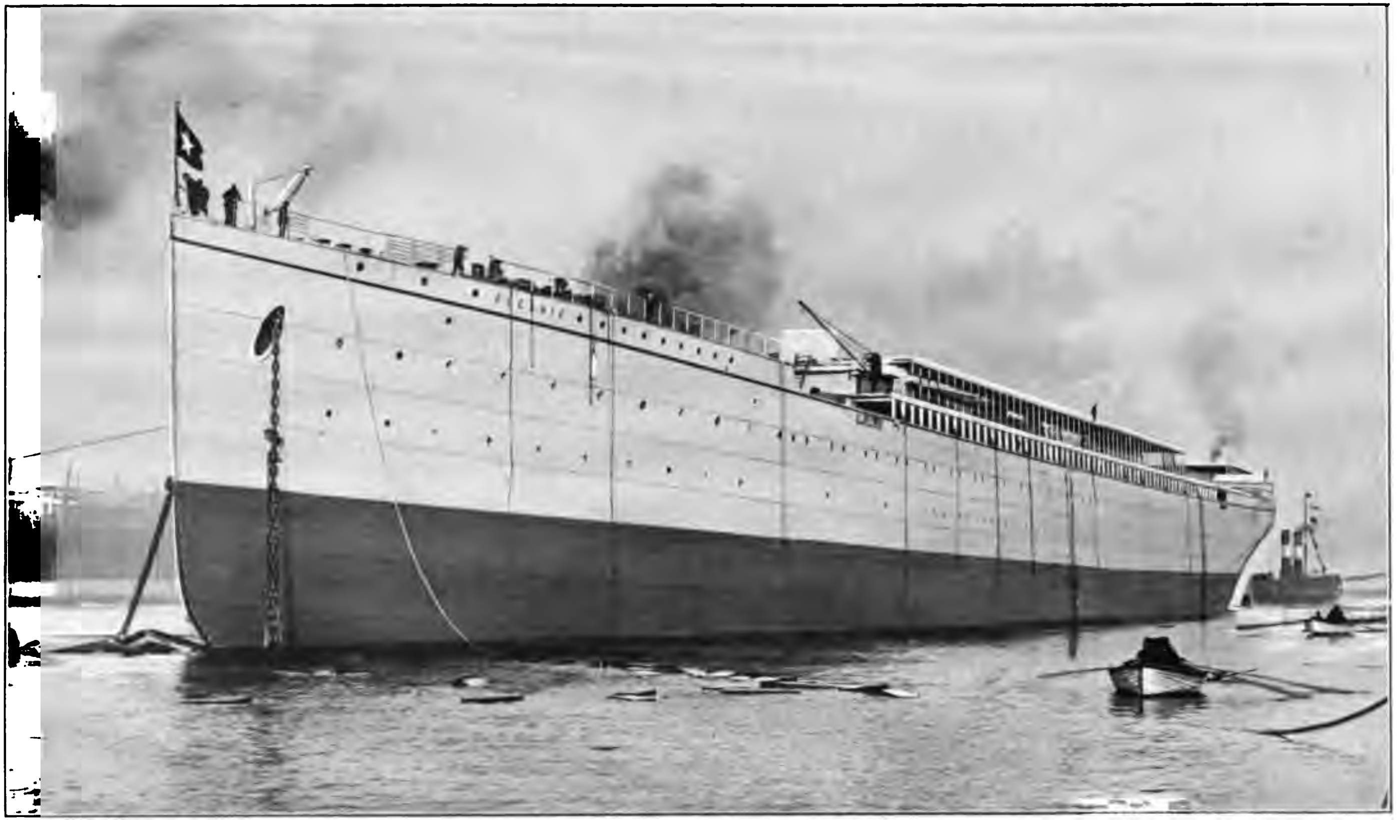
A. Vessel as she stands upon the launching ways, before the dog chocks are knocked out

B. Vessel in the condition when the after body becomes afloat

C. Vessel launched and afloat immediately after the cradle clears the ends of the standing ways

Fig. 177.—Launching Diagram.

PLATE IV.]



[*By permission of White Star Steamship Co.*

ROYAL MAIL TWIN SCREW PASSENGER STEAMER 'OCEANIC.'

JUST LAUNCHED.

Length over all, 705'-6"; length B.P., 635'-3½". Breadth Mld., 68'-2". Depth Mld., 49'-1".

times the cradle has collapsed through weakness, and the vessel has come heavily down upon her stem, thereby producing considerable damage. Because of this fact, more declivity is given to the after end of the standing ways than the fore end by cambering, the endeavour being to get the vessel over this critical stage as soon as possible, remembering at the same time that the resistance offered by the water increases as the immersion increases.

In calculating the condition of a ship with regard to tipping, the moment of the vessel's weight and the moment of buoyancy are calculated about the end of the standing ways. If, when the ship's centre of gravity passes over the end of the standing ways, the buoyancy moment falls below the moment of weight, tipping will, under such circumstances, inevitably occur. Care should be taken that a vessel has a reasonable margin of moment to ensure against tipping, *i.e.*, preponderance in buoyancy moment.

If the calculated results show that tipping is likely to ensue, something must be done to prevent this: either the launching ways must be lengthened so that the vessel becomes more deeply immersed when the centre of gravity passes the end of the standing ways, or else weight of some kind must be introduced into the fore end of the vessel; for instance, the fore peak might be filled with water. This will have the effect of reducing the ship's weight moment. Such a case could be further helped by increasing the declivity of the after end of the ways.

The danger of tipping is considerably less in full-lined vessels than in vessels with fine lines, the buoyancy moment naturally being proportionately much greater in the one case than in the other.

The danger of a ship coming to a standstill in her course down the launching ways may be caused by unfairness in laying the ways, or by too little declivity, or sinkage of the earth, or insufficient tallow in frosty weather.

CHAPTER VIII.

MAINTENANCE.

While too much care and attention cannot be given to the quality of the material used and the efficiency of the workmanship in the building of a steel or iron ship, yet, throughout her whole life, she demands incessant attention in order that she may be saved from the effects of the perpetual attacks of deteriorating agents, if she is to be maintained in a state of preservation and seaworthiness.

There are large numbers of vessels which, notwithstanding their enormous first cost, need extensive and expensive repairs before they are more than a few years old, this being, in many cases, entirely the result of carelessness and neglect.

As long as steel, iron, and wood are surrounded by a dry atmosphere, whether it be hot or cold, neither corrosion nor decay can arise. But as soon as damp air or water come into contact with them, unless protective measures of some kind be adopted, evidences of decay soon appear in a greater or less degree.

Wood,* as a rule, succumbs to the attacks of these forces by far the most rapidly.† As to the durability of iron as compared with steel,‡ there is still a divergence of opinion as the result of varied experiences, though the preponderance of weight seems to be against the comparative durability of steel. Perhaps, in many cases, this results from the fact being overlooked that, when steel is adopted, it is usually of less thickness than would be required for iron, owing to its greater tensile strength (indeed, the classification societies make due allowance in the reduction of the thickness of steel plates and bars), and, as a result, after corrosion has taken place, and the scale removed, the thinness or reduced thickness is more perceptible.

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* Teak, under favourable conditions, has been known to last 2000 years.

† It is quite true that there are wooden vessels afloat to-day of 50, 60, and even 100 years of age. But this in no way proves that wood is as durable as iron or steel for shipbuilding, for these aged wooden ships have been so often repaired or partially rebuilt, and decayed timber, fastenings, and bolts renewed, that in point of fact not much of the original wood remains, while in some localities the structure has been entirely renewed several times over. Steel and iron vessels also undergo extensive repairs in the course of their existence, but not nearly to the extent to which it is common to subject wooden ships.

‡ Note the supposed effect of manganese, which is proportionately more abundant in steel than in iron ('Manufacture of Steel,' p. 5).

Moreover, notwithstanding the fact that during recent years great permanent improvements have been made in the manufacture of steels—especially mild steels, such as are used for ship plates and bars—that perfection of manufacture has not yet been reached which guarantees the uniformity of quality even throughout a single plate or bar: for, subject to exactly similar conditions, it is not unusual to find that corrosion, often in the form of pitting,* proceeds more rapidly in one locality than another. It is also found that the rate of corrosion varies according to the constituent properties of the liquid in which the metal may be totally or partially immersed. Hence it is more rapid when subject to the action of salt water than it is with fresh. Then it must be remembered that the drainage from certain cargoes into the bilges may produce enormous and rapid decay. We thus see that corrosion may be accelerated either by the nature of the attacking agent or by the presence of certain elements in the composition of the metal itself.

Understanding the rapidity with which decay may progress in steel or iron when exposed to attacking agents, it is natural that shipowners, and all those responsible for the maintenance of steel and iron structures, should be alert to the necessity of discovering the most efficient means of so protecting those parts subject to deteriorating influences, as to preserve them from what must inevitably mean ultimate ruin. This protection is usually afforded, in a greater or less degree, by some kind of composition applied to the metal or material in liquid form.

Multitudes of 'anti-corrosives,' preventives, etc., have been patented and brought into the market, each claiming the qualities necessary to prevent corrosion or decay. However, while to specialize any particular manufacture lies outside the province of this book, to specify the quality which any composition must possess in order to prevent decay is not difficult. It must hermetically seal the surface upon which it is laid, making it both air and water tight. Any substance which does this will maintain and preserve the structure in question, and will continue to do so in proportion to the endurance it possesses, and the constancy of its attachment to the material it covers. The condition of the surface upon which the application has to be made is as important as the quality of the application itself. Lead and zinc paints, cements, vegetable and mineral tar, and zinc applied in the process of galvanizing, are among the principal materials employed in various localities in ships, subject to varying attacking forces, in order to preserve the structural strength and efficiency of the material by preventing decay.

When steel and iron plates and angles come first from the manufacturers, their surfaces are not always smooth and clean, but it may often be observed that they are covered with a scale of oxide of iron, or 'mill scale,' which at first very often clings tenaciously to the metal. To cover this with paint, or any other composition, would be worse than useless, for the only condition under which satisfactory results can be obtained is that the applied substance must come into direct contact with the metal itself, neither dirt nor corrosion nor moisture intervening. It is therefore absolutely essential that all mill scale be totally removed before the application is made. Otherwise, instead of corrosion being utterly prevented, it is allowed to proceed, and, eventually, this scale shells off, carrying its useless covering of paint or other matter with it. The wise thing, therefore, is to see that all this scale is entirely removed before any application is made. This is generally attempted in ordinary merchant shipyards by allowing the steel or iron to weather some considerable time —that is, to leave all the steel or iron work unpainted until the vessel is ready, before applying paint, etc. Experience, however, proves that this method is not altogether effective, and thus many owners, as well as the Admiralty, specify that all iron oxide be removed before the material is placed on the ship. This is usually done by means of a solution of hydrochloric acid in the proportion of one part of acid to nineteen of water. The plates are placed in this bath, and after remaining some time they are taken out, washed with fresh water, and scrubbed with steel brooms. They are then coated with raw or boiled oil, and allowed to bleach in the weather for some days. This process leaves the plate clean and smooth, and perfectly adapted for an application of the selected anti-corrosive composition.

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* Pitting—small pin-like holes in the steel or iron.

An important consideration before the application of any substance of the nature of paint is, that the surface of the iron or steel be thoroughly dry, as well as perfectly clean. Unless these conditions are fulfilled, the result will be far from satisfactory. Damp or moisture at once destroys, in a marked degree, the tenacity of such-like compositions. This consideration is more important than is often realized. It is a common practice amongst shipowners, trading on long ocean routes, to supply a quantity of paint or patent composition to their vessels, to be applied during or at some stage on the voyage. Nothing is more remarkable than the results produced. In one vessel it gives the utmost satisfaction: it neither cracks, nor blisters, nor shells off. It hermetically seals the surface of the metal, and only praise is bestowed upon it. Another ship will be supplied with identically the same composition, but a wide difference is experienced in the results. It blisters, cracks, and shells off, water is admitted and retained underneath the loose sheets of dry and useless composition, and, as a consequence, rapid and often extensive corrosion is set up, and the ship suffers more than she would have done had she been free from the covering. Such an experience is most markedly observed where weather decks have been covered in this way. In this vessel, the composition is condemned as worse than useless, and only complaints are lodged against it. Were the whole truth known, it is quite probable that, in many cases, the fault lies not with the application, but with the mode and conditions under which it is applied. Here, carelessness is as disastrous as neglect.

With increasing experience, the more impressed does one become with the truth that construction and maintenance are inseparably associated. To design the constructive part of a ship regardless of the fact that she will have to be maintained and preserved for many years after she is built, if she is to satisfactorily fulfil her calling, betrays unpardonable ignorance.

Strength is undoubtedly a foremost feature in the quality of a ship, but the maintenance of that strength is equally important, and to effect this preservation it is absolutely necessary that *easy* access be made to all parts of the vessel, in order to survey and examine, clean, paint, etc., whenever desired. The paramount question should be how much access can be given to ballast tanks, bilges, peaks, etc., without unduly weakening the structure, and not how little can be made to suffice. Whenever this latter method is adopted, the more liable are such parts to neglect. Those parts of a vessel which present the greatest difficulty and awkwardness in the means of access, are likely to be avoided and to receive the least attention at the hands of workmen appointed to deal with them.

The relation of construction to maintenance will be more fully observed as we consider sections of the ship in greater detail.

Maintenance of outside of Shell Plating.—If the vessel be new, and in the builder's hands, as has been pointed out, it is absolutely essential that all mill scale be removed, and that the surface be clean, and smooth, and dry before the paint is applied.

A common method of doing this is to leave the bottom unpainted when the vessel is launched. As soon as she reaches the water, a direct galvanic contact is set up between the mill scale and the steel. This action, which obviously tends to loosen the mill scale, is allowed to continue until the vessel is completed, when she is put into dry dock, thoroughly scraped, steel broomed, and washed with fresh water. When all—or as much of the mill scale as possible—has been removed, the bottom is given about three coats of quick-drying anti-corrosive composition.

The first of these should be applied in as thin a state as possible—almost pure oil. The next coat should have a medium, and the third, a full body. Ample time should be given between each coat to allow the composition to dry perfectly. The last coat is usually an anti-fouling paint.

When the vessel is not put into dry dock before leaving the builder's hands, she is usually allowed to run for a period not exceeding six months. She is then put into dry dock, and all paint that can be affected by an ordinary scraper is removed. The bottom should then be treated in the same manner as previously described.

If the vessel be an older one, and is being overhauled in a dry dock, and it is found necessary to paint her, all rust, old paint, dirt, and all fouling must be entirely removed by scraping or chipping. The new paint to be applied must come directly on to the dry metal surface. For a ship's bottom, below the load water-line, excellent results are obtained by applying hot zinc and tallow. Not only is this anti-corrosive, but anti-fouling, and in cases where this composition has been carefully and properly used, it has lasted for several years without any sign of decay in the metal. The disadvantage of this excellent composition is the great length of time required to apply it, especially if the weather happens to be wet or frosty. For the topsides above the load water-line, probably it is difficult to surpass red lead and oil, or red lead and white zinc mixed, applied with similar precautions in the usual way. Of course, to get these results, the zinc must be zinc, and the red lead must be red lead. We are inundated with so many patent compositions in these days, that it is not a little difficult to get the original or genuine article, unless a price is paid for it. And the huge differences in price at which zincs, etc., are offered, proves that much of it must be, as experience shows, pure rubbish, if such a contradiction may be used.

Vessels which are in the habit of lying aground in certain rivers or harbours to load or discharge at low tides, are subject to special injury from the unevenness of the stony bottom. The effect is, that the paint may be scraped off, and the bare surface of the plates exposed to the corroding action of the water. Corrosion always proceeds more rapidly wherever the surfaces of plates or angles are severely scratched.

In addition, boulders or large stones bearing against the edge of a butt or seam, may have the effect of springing the caulking, or straining the rivets, so as to admit water. Hence the importance of frequent examination of ships' bottoms, which are subject to such experiences as described.

If the shell is lap butted, care should be taken, when the vessel is building, that all the outside butt edges point aft, so that, in coming alongside a quay or landing, there is no chance of the plates catching against any projection. Some owners find it advisable also to chamfer the lower outside edges of the shell seam laps (which therefore point downwards) abreast all hatchways between the light line and the gunwale. This is advantageous to both ship and cargo when the latter is hoisted out of barges by the ship's winches and derricks, and dragged up the ship's side.

It frequently happens that vessels with bar keels trading over shallow sandy bars are found to have their garboard strakes and keel very much wasted by this continual grinding action. A means of safeguarding these important parts from destruction is to fit a shoe upon the keel as shown in fig. 178. To do this—as the illustration shows—a plate about ⅝ths thick is bent round the keel, and either tapped on (connected by means of tap rivets), or the rivets through the garboard and keel are taken out, and fitted long enough to go through the keel, garboard, and shoe.

In the old-fashioned system of making shell butt connections by means of straps instead of overlaps, the bilge strake butts frequently showed signs of working, and, in many instances, the caulking was corroded to such an extent as to leave a decided crevice.

Experience has taught that the best way in which to arrest this action is to keep the crevices well filled with metal stopping. Where this precaution has been neglected, the butts have, in some instances, become so wasted as to necessitate the fitting of outside straps.

In other cases, where weakness has developed at these butts, assistance has been given to the straps by fitting additional angle iron straps at right angles across the butt.

Topside of Steel or Iron Weather Decks.—Opinion and experience seem to favour the durability of iron as compared with steel for weather decks. But in both cases, corrosion, sometimes in the form of extensive pitting, takes place. It is scarcely necessary to draw attention to the importance of so arranging the deck plating that it will rapidly rid itself of water.

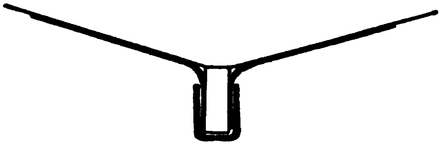


Fig. 178.—Plate Shoe on Bar Keel.

The strakes of plating from the centre line to the stringer plate, in unsheathed iron or steel decks, should be arranged in and out (see figs. 12 and 48), and not one in and one out, as is usually done under wood decks (fig. 58). To many shipowners, this corrosion of decks has been a sore trouble, and numerous attempts have been made to prevent it, with varying success. As previously pointed out, where these decks have been covered with an anti-corrosive composition, the effect in many cases has actually been to assist and encourage corrosion, owing to the application failing to grip the deck, and eventually providing a lodgment for water. The fault very often lies entirely in the carelessness evinced in making the application. Where a steel or iron weather deck is sheathed with wood, the metal may be well preserved by coating the clean, dry deck with a good covering of vegetable tar—Stockholm or Archangel, not mineral tar, unless refined so as to eliminate the ammonia. The wood deck should be laid hard down upon this, never upon battens in way of inside strake, and the seams well caulked with oakum. When the oakum has been properly inserted, the seam should be filled up with warm marine glue or vegetable tar. Butts should be dealt with in a similar manner. If this work is effectively carried out, water will only with difficulty be able to find its way through to the iron deck. But should such leakage through the wood sheathing happen from any cause, the deck is protected by the covering of tar. The bolts which pass through the deck and wood sheathing ought to be well bedded in white lead with dowels tightly fitted. This, again, will prove effective against the passage of water. When a wood deck is laid upon the beams, with no steel or iron deck, similar precautions are necessary, and the beams should be cleaned and thoroughly painted with red lead and oil. Sometimes a wood deck is badly disfigured by rust-coloured streaks in the region of the butts, owing to corrosion having taken place in the beams below the deck, and oozing up through the butt, promoting decay as well as disfigurement. It is specially necessary, therefore, to ensure the top surface of the beams being well coated with paint. Indeed, some owners specify that felt, dipped in red lead, be placed on the beams under all butts, and, in the case of yachts, where the whiteness of the wood deck is an important part of the beauty of the craft, zinc slips are sometimes fitted on the beams under all butts.

Owing to the generally acknowledged superiority of iron over steel in offering resistance to corrosion, it is becoming more and more customary to make all *exposed* weather decks—that is, those parts of uppermost decks unsheathed with wood, and not covered by poops, bridges, or forecastles—of iron.

Whenever a leak is found in the seam of a wood deck, or in the wood sheathing of a steel deck, the leak should never be treated locally with a caulking tool, as such treatment is almost sure to spring the seam on either side of the defective part, and perhaps make the leak worse than it was originally.

In all cases where it is found necessary to caulk a seam, the caulking should at least extend from butt to butt.

Occasionally, the seams of a wood deck show signs of creeping after being exposed under a hot sun, or after the vessel has experienced heavy weather. This may occur even though the deck may have been caulked but a comparatively short time previously. It is usual, under these circumstances, to note the seams where the pitch has a cracked appearance, and to caulk the worst ones right fore and aft, or to take every third seam and harden them down right fore and aft, and, if very soft, to put in an additional thread of oakum.

An easy method of finding the leaking or soft places in the seams of a wood deck is to watch the deck drying after it has been wetted. When the seams are good, they will dry as fast as the deck, but if there exist any defect, the water will linger in the seam for a considerable time after the other parts of the deck have dried.

In a sheathed deck, water will frequently find its way between the wood and the iron or steel deck below it. This is almost inevitable, notwithstanding the fact that great care may have been exercised in caulking the deck seams. If this water is allowed to remain, serious corrosion may result. As time goes on the rust will increase, the deck bolts will waste; it is highly probable that the wood deck will spring up, and more than likely that greater deterioration will occur than would have happened had the deck been left unsheathed.

To prevent water accumulating, a scupper pipe should be led to the bilges at the lowest part of the deck near the gunwale under the sheathing, so as to drain off the water.

This simple device may be the means of saving large and expensive repairs.

Many expedients have been adopted in order to preserve wood decks.

The commonest is to coat the decks with 9½ parts of raw oil to ½ part of terebene, and another is to use a solution of gum and turpentine.

Double Bottom Water-ballast Tanks.—Probably the structural parts enclosed in double bottom water-ballast tanks are more subject to the ravages of corrosion than any other part of the ship, and many reasons may be enumerated to show why this is so.

The best conditions under which the preservation of iron or steel may be effected are: either to keep the metal entirely dry, or entirely immersed Both these conditions are impossible in regard to the material constituting water-ballast tanks. As water is only carried as ballast when it cannot be safely or conveniently dispensed with, it follows that these tanks are alternately full and empty, and the material forming them alternately wet and dry, or partially so. This, therefore, is one cause promoting corrosion. Moreover, to pump these tanks absolutely dry is practically impossible. and, as a result, when they are supposed to be empty, the two or three inches of water in them is continually splashing and wetting the steel or iron, as the ship rolls and pitches. As most tanks are practically void of all ventilation, the air in them must be, in a greater or less degree, charged with moisture. Such conditions are found in a still more aggravated form under the boilers, where the heat produces a damp, steamy atmosphere, which is found to encourage corrosion to a most serious extent in a remarkably short time, unless special measures are taken to prevent it.

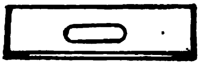
On surveying these tanks, signs of corrosion are more evident in some parts than in others. In M'Intyre tanks, excepting under the boilers, the wear and tear seems to be most prominent in the angles at the bottom of the fore and aft girders standing upon the floors. Signs of loose, and sometimes broken rivets, are found, especially in the side keelsons, caused probably by the movement of free water when the tanks are not full.

The under side of tank top plating, and, indeed, all the upper material, in these tanks, is more subject to corrosion than the lower material, probably owing to the greater amount of condensation which takes place in this locality.

In cellular-bottom tanks, the upper parts also are more subject to corrosion than the lower, especially the under side of the tank top plating, the reverse bars, and the upper fore and aft girder angles. Considerable wear is found at the limber holes in the floor plates. This no doubt is due to the wearing action of cinders, sand, or other rubbish finding its way into the tanks. The presence of stray bolts or rivets, which have carelessly been left in these tanks, sometimes produces a startling amount of damage, for, confined in a frame space, their action, when the tanks have been pumped empty, and the ship is rolling and pitching, has been, in some cases, to wear through a considerable thickness of cement, and actually through a thick keel plate.

The rate of corrosion throughout the double bottom is comparatively slight excepting under the boilers, where, if the greatest vigilance is not maintained, disastrous results occur. The heat from the boilers strikes through the tank top plating, and the warm stagnant air (efficient ventilation being exceptional), charged with moisture, produces a condition immensely favourable to rapid corrosion. For about a foot down from the tank top, and also between the floor manholes, this decay is found to be most excessive. Sometimes, vessels not more than four or five years old, through sheer neglect, have had the upper parts of their floor plates eaten entirely through. Double bottom tank margin plates often show rapid signs of corrosion, probably owing to bilge drainage.

Understanding the nature of the disease to which these tanks are subject, the important question is, to ascertain the most efficient means of prevention

As previously stated, the freest and most convenient access possible should be provided, for the simpler and easier the means of reaching every part of the tanks, the more likely is it that due attention will be paid in examining and dealing with them. Special attention should be given to the fitting and placing of the tank suctions, the aim being to empty the tanks as completely as possible, so that little or no water remains. The area of the water passages through the floors from floor space to floor space towards the suctions should be ample. The lowermost of these watercourses should be cut through the vertical flange of the frame bar and floor plate thus  and should not be more than three-quarters of an inch from the bottom of the tank (see fig.), so as to allow as much water as possible to drain towards the suctions. The sketch in fig. 173 illustrates the best form of suction mouthpiece for most entirely emptying a tank. It is made of galvanized cast iron, and is dropped into a cavity formed in the cement.

As the under side of tank top plating is particularly subject to corrosive action, accelerated largely by the prevalent conditions which inevitably exist and are so conducive to extensive condensation, iron is preferable to steel for this part of the structure, because of its greater required thickness and admitted superiority in resisting corrosion. Under the boilers, where the worst effects are experienced, it is advisable to adopt considerably thicker tank top plating than satisfies the requirements of Lloyd's Rules from a structural point of view. This method would considerably postpone what, under ordinary circumstances, would be extensive repairs to the inner bottom, because of the good margin of thickness.

Any method of ventilating or inducing a current of air would immensely reduce the obnoxious conditions existing in most of these tanks, and rid the space of the perpetual presence (when not entirely filled with water) of highly injurious atmosphere.

Some owners prefer to dispense with the tanks under boilers, and not close in the space as a watertight compartment. As shown in fig. 161, the tank top plating is dispensed with, allowing free communication at all times between the inside and the outside of the space. This idea is certainly all right from a purely 'preservation of material' point of view, as the space is greatly relieved from the injurious effects of damp and stagnant atmosphere, but it forms a serious objection from the ship safety standpoint, nullifying to a serious extent the immense value of a double bottom all fore and aft. Should the outer bottom in this space by any means be injured and the sea find ingress, the ship is most hopelessly crippled, even assuming that she still possesses sufficient reserve buoyancy to compensate for the loss of the boiler space buoyancy—which usually includes the engine space also—and that she is able to float in comparative safety. Her machinery is utterly useless, and steamers in these days are remarkably devoid of sailing equipment.

A double bottom only satisfactorily fulfils this, one of its chief functions, when it is absolutely continuous from the collision bulkhead to the aftermost bulkhead.

A much better plan is to construct the inner bottom continuous all fore and aft with a distinctly separate watertight compartment under the boilers, but to strictly exclude all water, and thus keep it always dry. In this way the tank could be wonderfully preserved by coating it with refined vegetable tar sprinkled with cement. Certainly it would reduce the capacity for water-ballast, as would also the previous method mentioned, but as the boiler space is usually comparatively small in cargo vessels, the reduction would not be very serious.

In any case, it is advisable to keep the boilers as high as possible above the tank top, say 2 ft., or 2 ft. 6 in., and by this means the heat is less seriously experienced. Some owners have found that considerable protection from the heat of the boilers is ensured by covering the tank top under the boilers with two or three inches of cement and tar.*

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* A system adopted by Messrs. W. Doxford & Sons, Limited, Sunderland, for the protection of the structural material under the boilers in double-bottomed vessels built for the Clan Line, is that of galvanizing the tank top, floor plates, intercostals, etc., in the region of the boiler room. This system is said to have produced highly satisfactory results, and although many owners might be inclined to object to the additional first cost, yet, if the intended object is accomplished, it cannot fail to be well worth the additional expense, and indeed prove in the end to be economical.

Whenever water is carried in these cellular-bottom tanks, perhaps the best protection is afforded by coating every part of their interior surfaces with a liquid of Portland cement and water applied with a large brush after the interior has been thoroughly dried and cleansed out and rid of all oxide of iron. This method, while commonly adopted, has proved very effective when *conscientiously* carried out, and repeated at such intervals as found necessary by examination.

Cementing.—In past years, before the double bottom system became so universal a mode of construction for cargo and passenger vessels, and the older ordinary floor system was still in vogue, considerable water or liquid found its way into the bottom of the vessel. This might be caused by sweating in the holds, or drainage from the cargo. In most ships, and especially in those carrying certain cargoes such as copper ore or sugar, which are particularly injurious to iron or steel, it has long been the custom to put a substantial covering of a mixture of Portland cement and sand or brick dust over the inside of the bottom plating from bilge to bilge. This cement was thick enough to amply cover the plating and rivet heads, and the frame flanges upon the shell, and afforded excellent protection from the effects of cargoes, such as we have indicated.

While this system of cementing is more desirable in vessels with ordinary floors, where all drainage finds its way on to the bottom plating, there seems little or no reason for practising it to the same extent on the bottoms of vessels inside the tanks where double bottoms are fitted.

Indeed, there is much to be said against it. In the first place, no bilge drainage of any sort can find its way inside a double bottom tank. The bilges on each side of the outer wings of these tanks, and sometimes specially prepared wells, are the reservoirs for all such drainage, and therefore the original reasons for using this cement no longer exist inside the double bottom tank. The weight of this cement amounts to scores of tons in vessels of moderate size, which necessarily represents an equivalent loss in deadweight. The vessel is therefore handicapped with a perpetual and unnecessary burden. Moreover, this cement, instead of being a source of protection, may prove a source of actual injury to a ship, unless the most rigorous inspection be maintained, and frequent surveys instituted.

As we have mentioned previously, considerable injury may be inflicted upon the outside bottom of a vessel lying aground to load or discharge. But even when little or no trace of damage is apparent from the outside, owing to the utter inflexibility of the cement, it may have become cracked and loosened, and while almost if not entirely undetectable by eye, it permits water to ooze through and lodge against the shell of the vessel, and the mischief is not discovered until serious damage has been done. Even the slightest working of a vessel which never touches the ground with her keel under any circumstances, may crack the cement. If this cementing is confined to the keel plate, and at most over the garboard strake on each side, where cinders or other foreign matter which accidentally get through the manholes may exert considerable friction against the bottom, it ought to prove sufficient. All other parts of the interior of these tanks should be well coated with cement wash, and re-coated at intervals.

Outside of Inner Bottom Plating, Bilges, and Wells.—In order to best preserve the hold surface of tank tops, as we observed in decks, a foremost consideration should be to render the lodgment of water an absolute impossibility. In building a double-bottom tank according to Lloyd's requirements, the depth of the centre girder or centre keelson, and the width of the margin of the tank, are fixed by rule. It is not a little surprising, however, what amount of ingenuity has been exercised (often purely economic) in manipulating these two fixed dimensions, and in producing, in similar ships, tanks of vastly different capacity and shape. The general system which used to be followed was to set off the depth of the centre girder, lay the tank top plating horizontally over this, and extend it in each transverse direction, until, by striking a straight line perpendicular to the bilge, the required depth of margin was obtained. By lowering the transverse extremities of these tank tops two or three inches, so as to give an inclination towards the bilge and thus assist the drainage of any water in that direction, probably the most satisfactory double-bottom tank to all concerned is produced. (See figs. 12, 48, etc.)

Until recently, the almost universal custom has been to cover this tank top plating with broad deals of timber (ceiling) in a fore and aft direction over wooden grounds arranged athwartships. Where this is done, the tank top strakes of plating are usually arranged in the same manner as steel decks under wood sheathing,—alternate strakes in and out, unless the reverse bars are joggled, or the edges of the strakes of plating flanged. As this ceiling is not usually caulked, but simply clamped together, it is necessary to protect the plating by some efficient covering. This is often satisfactorily accomplished by applying a good coating of vegetable tar, or specially refined coal tar sprinkled well with cement. Where this is carried out with all due precaution, the tar will serve its purpose for years, and leave the iron as clean as ever. However, as is now being discovered, under many circumstances this wood ceiling is utterly useless in a ship's hold, costing money, adding weight, occupying space, and often harbouring water and dirt beneath it. It has now become a frequent practice to dispense with it.

The strakes of plating are arranged like those of an unsheathed weather deck, each strake in and out like the slates on a house roof, and, with the slight declivity previously recommended, any water flows off into the bilges. (See fig. 48.) The continued friction of loading and discharging cargo keeps the tank top plating clean and smooth, and generally neither paint nor covering for purposes of protection is necessary. Sometimes, by giving the tank top an abnormal declension towards the bilges, and a fair rise of floor, it is surprising how small and useless the double bottom may become, for the width of the tank side can only be obtained at an absurd distance from the bilge. True, considerable saving can be effected in the weight of iron or steel in the construction of the tank, but the capacity of the tank is seriously reduced for the carriage of water-ballast, and its efficiency as a double bottom greatly minimised owing to the tank covering only part of the breadth of the ship's bottom.

When tank tops are left unsheathed with ceiling, they are usually protected immediately under the hatches with a covering of wood battens, which are surrounded and held in position by an angle bar riveted to the plating. The reason for this is obvious. Sometimes, in lowering heavy weights into the hold, they are allowed to bump on to the tank top, and were it not for the protection already described, considerable injury might be done. Even though the plating itself were not seriously damaged, caulking, rivets, or butts might be sprung, so as to destroy the watertightness of the tank. Sometimes, even where the precaution of protecting the tank is adopted, or the whole area covered with ceiling, carelessness in loading cargo, or the accident of a heavy weight falling, may cause the same injury.

In cases where the rise of floor is very great, were a horizontal or nearly horizontal top to be given to the tank by adopting the rule minimum width of margin on tank side, the tank would be extremely narrow, and thus only partially cover the bottom, and moreover, contain only a comparatively small quantity of water for ballast. In such a case, a method has sometimes been adopted of raising the tank top from the top of the centre keelson, toward the bilges. By this means, any water finding its way on to the tank top would flow towards the centre line (the lowest point) and thence into a well at the after end of the hold space. Here again, the strakes of plating should be arranged like the slates on a house roof, each in and out. The idea is simply to get rid of all water in the most rapid manner.

Bilges.—Few, if any, parts of a ship are of more vital importance than the bilges. These form the drains for the holds. All sweat moisture, all moisture from cargo, even rubbish, and sometimes water from scuppers, find their way into the bilges. The result of the combination, depending much upon the nature of the cargo, is often a liquid possessing tremendous propensity for attacking and corroding iron or steel. Where the material in these bilges has not been adequately protected, vessels carrying cargoes such as copper, sugar, rice, in a single voyage have evinced remarkable decay. Hence the necessity for frequent inspection, and the readiest and simplest means of carrying out this operation. The most prevalent arrangement of covering in the bilges to prevent, as far as possible, cargo or dust finding its way into the space, is to extend the ceiling over the bilges to the ship's side. Entrance to the bilges is obtained by lifting a fore and aft plank. (See fig. 64.) A better arrangement is that shown in fig. 179, where the bilge coverings consist of iron hinged shutters, occupying less space, and obviously much handier, not to mention the better view obtained for examination when they are lifted, afforded by the full exposure of the bilges. The pump suctions in the bilges should be carefully placed so as to rid the space of water as effectively as possible. Here, perhaps, more than anywhere else in the vessel, cement should be liberally applied. The shell and tank side should be thoroughly coated, and the bilge filled with cement up to the level of the drain holes in the tank bracket plates. The cement should be very smoothly laid, so that the water may find its way without any obstruction to the suctions. Only by carefully carrying this out, and frequently surveying this space, can this part of the vessel be saved from rapid decay.

Wells.—Sometimes the drainage from the holds is allowed to accumulate solely in the bilges, from whence it is pumped. Often, however, the bilge water is drained into wells (see fig. 174), from which steam suctions are led for its discharge. These wells are usually situated at the after end of a hold space, or engine and boiler space, and extend from bilge to bilge with a length of about two frame spaces (4 ft.). The two ends forming the extremities of the adjacent water-ballast tanks are, of necessity, strictly watertight. This well space is a watertight compartment, excepting that a few (about three) holes are punched in the tank side plate near the bottom of the bilge, which allow the bilge water to drain into the well. Being subject to the same wasting forces as are found in the bilges, these wells require similar treatment for their protection. The chief objection to them is that they interrupt the continuity of the watertight double bottom,

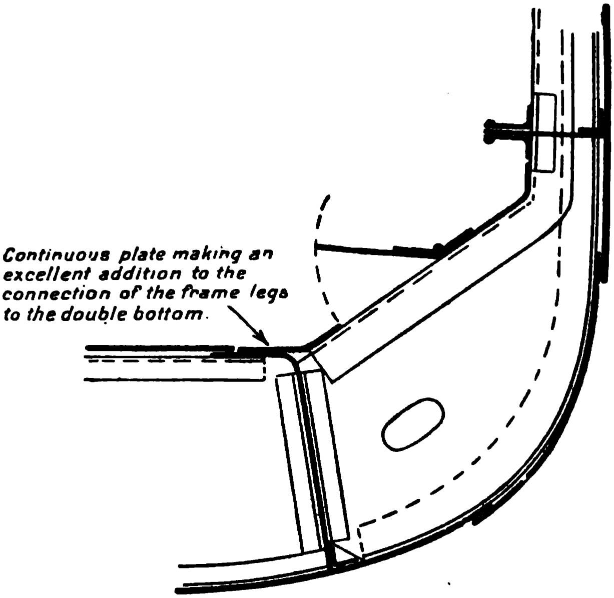
Continuous plate making an excellent addition to the connection of the frame legs to the double bottom.

Fig. 179.—Hinged Bilge Shutters.

and thus, should damage happen to the outside plating in the way of these wells, free access is opened to the large hold spaces, and the advantage of a continuous inner bottom is lost, and its value therefore decreased.

Hold and 'Tween-deck Spaces.—On examining the under side of steel or iron decks, the shell plating, and the framing in the holds of steel vessels, one is sometimes surprised to discover to what extent corrosion may be found in a place so exempt from weather. The under side of decks, beams, beam knees, frames, and especially reverse frames, as well as the shell, are liable to extensive corrosion. Keenly alive to this fact, many of those responsible for the maintenance of iron and steel vessels, make vigorous and commendable efforts to save their vessels from the disastrous effects which, unless effectively dealt with in time, inevitably ensue, utterly ignoring the cause of the trouble. Everyone knows that to close up the doors and windows in a room, and permit little or no ventilation, will result in damp and sweating on walls and windows, or any other cold surface, and especially will this be noticeable if the atmosphere be subject to any slight heating. To get rid of this undesirable state of affairs, a current or draught of air must be obtained by some means or other. Or, in other words, good ventilation is necessary. Ships' holds produce similar results under similar conditions. These spaces in hosts of cargo vessels are badly and inefficiently ventilated, and with such a large area of naturally cold surface, condensation or sweating upon beams, decks, frame, shell, etc., to an enormous extent, is the result, often causing damage to the cargo. In ships where ventilation has received adequate and intelligent attention, sweating is almost unknown, and little or no injury is inflicted upon cargo and hull. It is not so much continual scraping and painting that is required, but perpetual and efficient ventilation in these spaces to dispose of this evil.

The more that air is induced to circulate through the holds, the less ill effect is likely to be experienced by the ship and cargo. For miscellaneous cargo, oil, and coal-carrying vessels, good and abundant ventilation is of the very highest importance. By thoroughly cleaning the surfaces of all plating and angles, and coating with red lead and oil, repeating the operation as the wear and tear of the vessel indicates, there ought to be little difficulty in throughly maintaining and preserving all iron and steel exposed in the holds. When sweating does occur, it should be seen that no pools of water lodge upon hold stringers, or any such like projecting material. Small holes drilled or punched in these places will allow the water to find its way down into the bilges. Crevices or corners which are likely to harbour water or dirt should be filled with cement.

The shell plating in the hold or 'tween deck spaces in the neighbourhood of all side scuttles should be subject to periodical inspection, as leakage may possibly occur, and thus promote decay. Hence the cleading on the ship's sides in the 'tween decks of passenger steamers should be partially removed at intervals, where the danger of such leakage exists.

Bunkers.—Bunkers are another locality in a ship which should receive adequate attention. The gas emitted from coal seems to have a specially injurious effect upon iron and steel, particularly the latter, if the surface is not protected by some suitable covering. Various compositions are found to do this effectively, while other owners get every satisfaction by coating their bunkers with refined vegetable tar, and others by bituminous cement. Ordinary paint rarely proves efficacious for any length of time against the special conditions existing in bunkers.

Fore and After Peaks.—Fore and after peaks, when only used for cargo or stores, should be kept as dry as possible. The deep recesses between the floors would render this very difficult, were it not customary to fill the lower extremities of these spaces with cement. Indeed, wherever awkward recesses exist, in which water would be likely to lodge, or whatever small spaces are found to be difficult to get at for examination, the better plan is to fill up these crevices with cement. If the peaks are used for water-ballast, probably a thorough coating of thick cement wash, or refined vegetable tar, will prove as good a means of preservation as anything. When the space is only used for stores, or perhaps cargo, good paint will give the necessary protection. Here, again, too much importance cannot be laid upon the ventilation of these spaces. No preventive or anti-corrosive will stand as well where the atmosphere is foul and stagnant, and those who know anything about peaks will be aware that so utterly polluted, and filled with poisonous gases, are these places in some vessels, that when first the manholes or hatches are removed, neither lamps nor light will burn inside, and to enter them would mean certain death. Indeed there are cases on record of such disasters occurring.

Deep Water-ballast Tanks, also used as cargo spaces.—Like double-bottom ballast tanks, these compartments are subject to alternating wet and dry. The importance of an abundant and well-arranged system of ventilation must be obvious in order to get rid of all moisture and damp atmosphere as early as possible, after the tanks have been pumped empty. No doubt much damage is done to all kinds of water-ballast tanks, owing to the fact that they are not always filled to the uttermost when used for ballast. When completely filled, the mass of water has no more injurious effect than a well-stowed cargo, but where tanks are carelessly left partially filled, it is difficult to estimate what damage may not be done. Bulkheads may be ruptured, rivets loosened and broken, caulking destroyed, and cargo in adjoining hold spaces seriously damaged. These tanks can be made perfectly watertight, thoroughly reliable, and most satisfactory, and of tremendous advantage to vessels going to sea without cargoes. And yet more than one owner has dispensed with them, because of the trouble they have caused. Such trouble can only arise from workmanship and construction, or else gross carelessness on the part of those who have charge of them—most probably the latter. Deep ballast tanks are being more adopted than ever in ocean steamers, and with due care and attention in construction and in treatment, they can be maintained with comparative ease. Refined vegetable tar or refined coal tar has proved to be a good protecting agent in the maintenance of these tanks.

Corrosion owing to Galvanic Action.—The proximity of certain metals to iron or steel may set up galvanic action, and, consequently, promote corrosion. Hence when bronze propellers are fitted, unless suitable precautions are taken, severe pitting is created in the stern post. This galvanic action may be counteracted by tapping thin zinc slips to the aperture surface of the stern frame.

A peculiar feature in cast iron propellers after being in use for any considerable time is the excessive pitting which takes place on the back of the propeller blades. Opinions are numerous as to the cause of this, but no definite explanation can be given. However, by riveting thin brass plates on to the back of the blades of cast iron propellers, protection is afforded and such injury obviated.[*]

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[*] Shipowners might save themselves enormous expenditure for repairs, etc., if more attention, systematically carried out, were conscientiously given to their vessels. Much of the deterioration and decay is entirely the result of neglect which might be greatly prevented, if, in addition to the ship superintendent, whether he be a naval architect, an engineer, or a ship's officer, another appointment were instituted in large companies by which a man, thoroughly acquainted with ship construction and the particular localities in ships liable to decay, could give his whole attention to this matter. The ordinary ship superintendent of a fleet of vessels has too much other work to attend to in the performance of his duties to give the attention which is necessary for the preservation of the vessels entrusted to him. Where this vitally important work is left in the hands of ill-paid or irresponsible persons, neglect to hidden parts to which it is difficult to obtain access ensues.

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